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Characterization of Painted Surfaces in the United States from the Perspective of Potential Damage from Acidic Deposition

Brookhaven National Lab., Upton, NY

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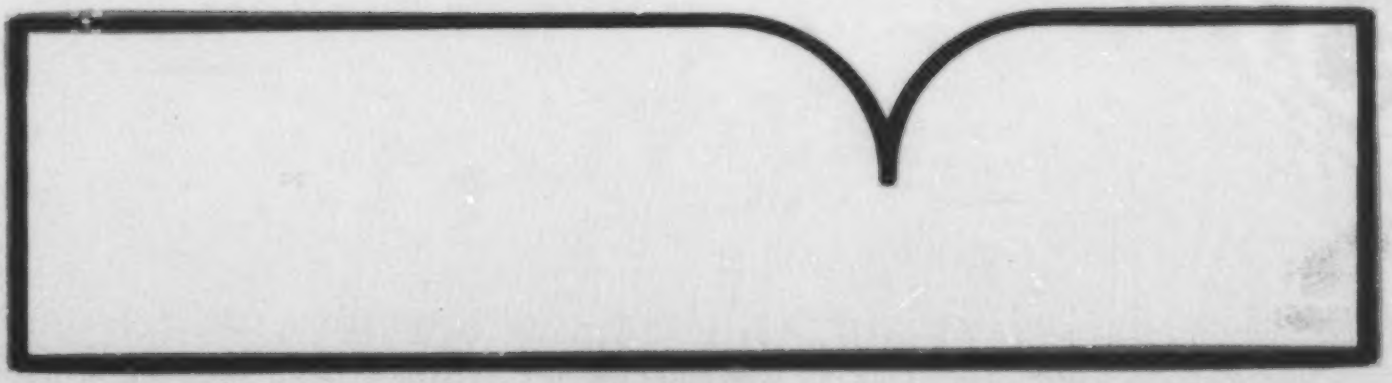

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CHARACTERIZATION OF PAINTED SURFACES IN THE UNITED STATES FROM THE PERSPECTIVE OF POTENTIAL DAMAGE FROM ACIDIC DEPOSITION

by

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16. ABSTRACT

Data on the types and applications of exterior paints used in the United States are reviewed from the perspective of potential damage by air pollution or acidic deposition. The data indicate that, of the painted structures in the U.S., the costs of painting residential buildings are the most economically important subset. The trends for new construction indicate that this ranking is likely to continue in the future. Although both new construction and maintenance painting are economically important, the more difficult conditions involved in painting over existing finishes make this an important class for research. The most important mode of paint failure appears to be "peeling", which, in its various manifestations, accounts for about half of residential paint problems. Such problems often occur within two to three years after painting. Although chalking and erosion have been observed, their roles in decisions to repaint are less apparent. Paints containing acid-sensitive components may be found in today's retail market at all price ranges, especially oil-based glossy paints. Painting solely to change color or for resale, of the property appears to be of minor importance. The report recommended that selections of coatings and substrates for acid deposition research should include both those combinations that are widely used (latex over wood and over previous paint) and that are sensitive to acid deposition (paints containing $CaCO_3$; alkyd over steel).

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SUMMARY

Data on the types and applications of exterior paints used in the United States are reviewed from the perspective of potential damage by air pollution or acidic deposition. The data show that residential buildings are the most economically important subset of the painted structures in the U.S for painting costs. The trends for new construction suggest that this ranking is likely to continue in the future. Although both new construction and maintenance painting are economically important, the more difficult conditions involved in painting over existing finishes make this an important class of situations for research. Automobile finishes are a high-value use of paint, but the importance of acid deposition as a reason to repaint has not been established.

Consumer surveys show that the most important mode of paint failure is peeling and flaking, which, in its various manifestations, accounts for about half of residential paint problems. Such problems often occur within two to three years after painting. Color changes (deterioration) are next in importance. Although chalking and erosion have been observed, their roles in decisions to repaint are less apparent. Paints containing acid-sensitive components may be found in today's retail market at all price ranges, especially oil-based glossy paints. Painting solely to change color or for resale of the property appears to be of minor importance.

The trends in paint usage and performance are generally supportive of (or not inconsistent with) the hypothesis that air pollution or acid rain may be having some adverse effects, although such data are by no means conclusive. The report recommended that selections of coatings and substrates for acid deposition research include those combinations that are widely used (latex over wood and over previous paint) and those that are sensitive to acid deposition (paints containing $CaCO_3$; alkyd paint over steel).

SECTION 1

INTRODUCTION

Preliminary assessments have indicated that painted surfaces constitute perhaps the most abundant group of structural components in the United States that might be sensitive to the deleterious effects of air pollution and acid deposition (Lipfert, 1987; Lareau et al., 1986). For this reason, the National Acid Precipitation Assessment Program (NAPAP) has implemented a research component with the goal of quantifying such adverse effects (Spence and Haynie, 1987). Since the adverse effects in question are primarily economic rather than aesthetic, it is important to conduct these characterizations in economic terms. A part of this program is the identification of the most important types of paints and structures to be studied. Such a selection process must recognize two distinct criteria: (potential) sensitivity to acid deposition, and relative abundance in the US economy.

For the purposes of this report, we define "acid deposition" as both precipitation-borne and air-borne substances which are either acidic or can become acidic after deposition on a surface. Note that this definition includes both "clean" rain, which is actually a weak solution of carbonic acid with a pH of 5.6, and gases such as sulfur dioxide which can dissolve in moisture films on surfaces to form acids.

This process is necessarily somewhat circular, since research is required to demonstrate adverse effects of environmental exposure and thus sensitivity. However, preliminary findings based on both direct and indirect evidence provide a useful starting point. The direct evidence (Edney, 1988) consists of chemical analysis of precipitation after it has passed over test samples painted with various types of paint. The presence of paint constituents, such as Zn^{++} (from ZnO) or Ca^{++} (from $CaCO_3$), in the runoff indicates a leaching attack by the precipitation. The indirect evidence (Haynie, 1985) consists of correlations of changes in weight of painted test samples over time versus environmental parameters such as SO_2 deposition.

This report comprises two main sections. The first characterizes the population of painted surfaces or structures "at risk" in the United States, with an attempt to provide a regional breakdown according to regional acidic deposition characteristics. The second section characterizes modes of failures of paint coating systems, from the perspectives of both laboratory tests and consumers' experience. The sources of data we have drawn upon include U.S. Census Bureau statistics, personal contacts with knowledgeable individuals in the paint industry, and results of consumer surveys.

Following these sections, recommendations are presented for specific coating/substrate combinations to be studied as part of the program of research on the effects of acidic deposition. An appendix is included giving common definitions of terms used to describe failure modes of coating systems.

SECTION 2

CHARACTERIZATION OF THE POPULATION AT RISK

TYPES OF PAINTS IN USE IN THE U.S. AND THEIR APPLICATIONS

Definitions and Classifications

In general, paints are classified according to their ingredients and their intended functions. Since in this case we are interested only in exterior applications, the two functions of interest are beautification and protection of the underlying surface or substrate from the environment.

Paint coating systems comprise three main functional components:

1. the pigment, which provides color or "hiding."

2. the polymer (resin) film-former, which binds the pigment to the substrate.

3. extenders or thickeners, which add body to the coating and allow small surface imperfections to be filled in.

These components will vary according to the application and purpose of the paint.

By application, the industry (and the Census of Manufactures through their SIC product codes in the 2851 group) recognizes three broad categories, each with a number of subdivisions. Since we are interested in those applications with potential exposure to acid deposition, we have identified those subdivisions which meet this criterion:

1. Architectural coatings (SIC=28511):
exterior paints and stains (solvent and water based). Light duty maintenance paints may be included in this category.

2. Product finishes for original equipment manufacturers (OEM) (SIC=28512):
prefinished wood siding; automobile and other transportation equipment finishes; sheet, strip and coil coatings, including siding but excluding containers.

3. Special purpose coatings (SIC=28513):
exterior industrial maintenance paints, automotive refinish paints, traffic marking paints.

Within these application classifications, there are also paint formulation subdivisions. Perhaps the best known of these is for architectural coatings according to the type of resin and solvent: oil or solvent-based paints, and latex or water-based paints. Automotive paints

are often subdivided according to lacquers and enamels; traffic marking paints, according to their thermoplastic properties. We have not found these latter subdivisions particularly useful for this analysis.

RANKINGS OF THE MAJOR PAINT APPLICATIONS

Methods

The economic value of a given type of paint should include the costs of surface preparation and application, which are usually substantial multiples of the costs of the paint materials per se. In this section, we draw on Census data and data from various consuming sectors in order to estimate the economic rankings of various paint coatings systems and applications, exposed to the outdoor atmosphere.

Factory Shipments

The factory shipment and cost data are taken directly from the Census of Manufactures; we have implicitly assumed that US production equals US consumption, since both imports and exports are small percentages for these product classes. The range in factory cost per gallon is from $5 per gallon for traffic paints to over $20 per gallon for automotive and machinery refinishes; retail costs are much higher because of distribution costs and markups.

Application Costs

The value of a protective coating system as installed, the "in-place" value, includes the costs of surface preparation and installation. For a factory-applied finish, an equivalent value can be estimated from the cost of refinishing the item after it is in service.

The in-place value data have been estimated as follows. For architectural paints, the labor is estimated from Means (1985), which gives a figure of 0.017 man-hours per square foot for applying primer and two coats of exterior paint (new construction). Based on contractor labor billed at $40 per hour (which includes the contractor's profit and overhead) and a paint coverage of 400 gal./ft^2 per coat and material costs of $28 per gallon (retail), the total is $119 per gallon. This figure is for new construction using contract labor.

A large percentage of residential painting is done by property owners (62% according to Connolly et al. [1984]), for whom the appropriate labor costs (the "opportunity" costs) may be lower, but such painting also requires substantially more preparation time than new construction. The data of Weber et al. (1985) indicate that surface preparation approximately doubles repainting costs relative to new construction. We have assumed that these two factors are offsetting and used the same per gallon value for all exterior architectural paint. By way of comparison, Weber et al.'s cost on a per gallon basis is $140; two residential painting jobs known to the author involving very intricate trim painting were in the range $160-260 per gallon, adjusted to average US labor rates. Thus our figures for the annual in-place value of architectural coatings may be somewhat low.

For automotive refinishing, we have used an estimate of $500 as the cost of repainting an "average" car with no body damage, requiring two gallons of paint, including primer, for an average of $250 per gallon. However, as published by the Census of Manufactures, this category of factory paint shipments also includes "other transportation and machinery" paints, which must account for a large part of the volume, since at two gallons per car, the shipment

volume would correspond to repainting 22 million vehicles per year (14% of total registrations), which seems high. It also follows that some portion of this category (machinery) may be indoors.

For painting of new (original equipment manufacturers [OEM]) transportation equipment, in-place costs could not be estimated since they are largely dependent upon capital equipment rather than labor costs. However, the value of new car finishes was estimated by using the cost of refinishing. The Census figure for 1987 new car paint production (55 million gallons), when combined with estimated annual new vehicle production (about 10 million cars), implies substantially more paint per vehicle than for refinishing, but is consistent with Reisch's (1988) estimate (6 gallons per vehicle). Since new car painting also involves undercarriage and interior painting, we conclude that only about a third of new car paint is exposed to the outdoor atmosphere.

The costs of applying coil coatings and maintenance paints are more difficult to estimate. We assume that the in-place value of a coil coating such as painted roofing or siding is the cost of replacing the coating once it has deteriorated. Such replacement involves substantial surface preparation but probably sprayed-on finishes. Weber et al. (1985) show lower costs per unit area for spraying than for brushing, which may compensate for some of the preparation cost. A case study of roof refinishing in Illinois gave a unit cost of $\$0.57/ft^2$ for three coats and surface preparation (Metal Buildings Review, 1985). This translates to \$76 per gallon. More recent cost estimates for refinishing metal roofing and siding were in the range $\$1.20\text{-}2.40/ft^2$, depending on the configuration and level of rust (Weiss, 1988). Another case study is afforded by a recent contract to repaint the Newport Bridge, which has a span of 1600 feet. These figures worked out to an average of about \$80 per gallon, using a three coat system. For the purposes of this analysis, we used \$100 per gallon for both coil coatings and maintenance paints.

Another category of factory-finished materials exposed to the outdoor atmosphere is prefinished wood products, such as siding. The total paint shipments in this category in 1987, for both interior and exterior use, were only about 6.4 million gallons and the category has been decreasing over time. We have therefore elected to not consider this category further.

The in-place value and replacement cycle of traffic paints may be estimated by assuming 400 ft^2/gal. coverage and four 4-inch stripes per mile of road (17.6 gallons per mile). Attaway and Babcock (1988) give an installed cost of \$0.03 per foot for a 4-inch stripe, which translates to \$36 per gallon. Since there are about 4 million miles of roads in the US, we then conclude that highway striping is replaced about every 3.5 years. Conversations with highway officials suggests that in the eastern US, replacement is needed as often as annually. A possible source of underestimation of the annual usage of traffic paint is the manufacture of such paints by states, using prison labor (Medford, 1988). However, even if the annual production volume were doubled, the in-place value of this category of paints would still be small in relation to architectural coatings. Sensitivity of this type of paint to acid deposition is discussed below.

Quantities and Values-in-place

Table 1 presents preliminary data from the 1987 Census of Manufactures (Reiner, 1988) for outdoor applications of paint. Shipment volumes (million gallons), factory values (million dollars), and in-place values (billion dollars) including estimated mark-ups and application labor are given, based on the estimation methods discussed above.

The annual in-place value of architectural coatings is the highest category, followed by automotive (and other transportation equipment) paints. Maintenance paints, coil coatings, and traffic marking paints account for substantially lower in-place values. The ranking of automotive finishes must be discounted by the high proportion of painting done to repair body damage, rather than because of paint failure. Considering that a car may be 10 years old or more by the time its refinished paint nears failure, extending the life of this paint would appear to have only marginal value relative to the value of the car.

By way of confirmation of the relatively low rank of maintenance painting, a 1977 input-output analysis of the US construction industry (Williams, 1985) estimated $147 million for maintenance painting costs to nonbuildings, and $1.1 billion for buildings. In addition, Frondistou-Yannas (1980) estimated the annual (1979) national expenditure for corrosion protection of highway bridges at $130-160 million, and that this was about half of what was required for adequate corrosion protection. Even after accounting for inflation, this category of painting would not rank high in Table 1. This conclusion is also confirmed by Vacha (1985), who reported bridge coating expenses of $45 million in 1980, expected to reach about $100 million by 2000. (The costs of bridge failure due to inadequate maintenance have not been considered, however; a 1984 estimate of spending on new and rehabilitated bridges, excluding maintenance, was about $5 billion [Roads and Bridges, 1984].)

ANALYSIS OF ARCHITECTURAL PAINT USAGE

Since the environmental exposures and types of paint used for architectural coatings vary by application, it is useful to try to derive a more detailed breakdown. The 1977 Input-Output Profile of the Construction Industry (Williams, 1985) is useful in this regard. Figure 1 shows the breakdown of the total 1977 U.S. Construction industry output (purchases plus value added), which amounts to $267 billion. of this total, residential construction output totals $110 billion, of which about 18% is maintenance expenditures (Figure 2). Maintenance and repair expenses of all kinds are broken down in Figure 3, and expenditures by property owners in Figure 4. "Do-it-yourself" labor is not included in these latter figures.

Figure 5 presents the overall breakdown of sales of "paints and allied products" for 1977, of which about 46% was accounted for by construction. The distribution of paint sales within the construction industry is shown in Figure 6: residential maintenance accounts for about 25% and other maintenance work adds another 18%. New single family housing and residential alterations are the other large categories, at about 20% each. These figures are for the costs of materials only; assuming that the labor costs per gallon are roughly equivalent, the percentages would also apply to the total costs of painting. On this basis, the residential sector is by far the most important, followed by other types of buildings (commercial, industrial, and institutional), and then by non-building structures. Another split of interest is that of new construction (56%) versus maintenance (44%), for paint materials in 1977. Taking into account the higher labor costs for surface preparation for maintenance painting, the total costs are likely to exceed those for new construction. The corresponding

Table 1. 1987 Paint Shipments and Associated Costs
(exterior uses)

Classification	Shipments million gal.	Factory Cost million $	In-place Value billion $
Arch. Coatings			
Oil-based	80	$807	$9.5
Water-based	123	944	14.6
Automotive Finishes			
new vehicles	73	1323	6.
refinishing	44	904	11.
Coil Coating	20	303	2.0
Industrial Maint. Paints	28	313	2.8
Traffic Marking Paints	19	95	0.7

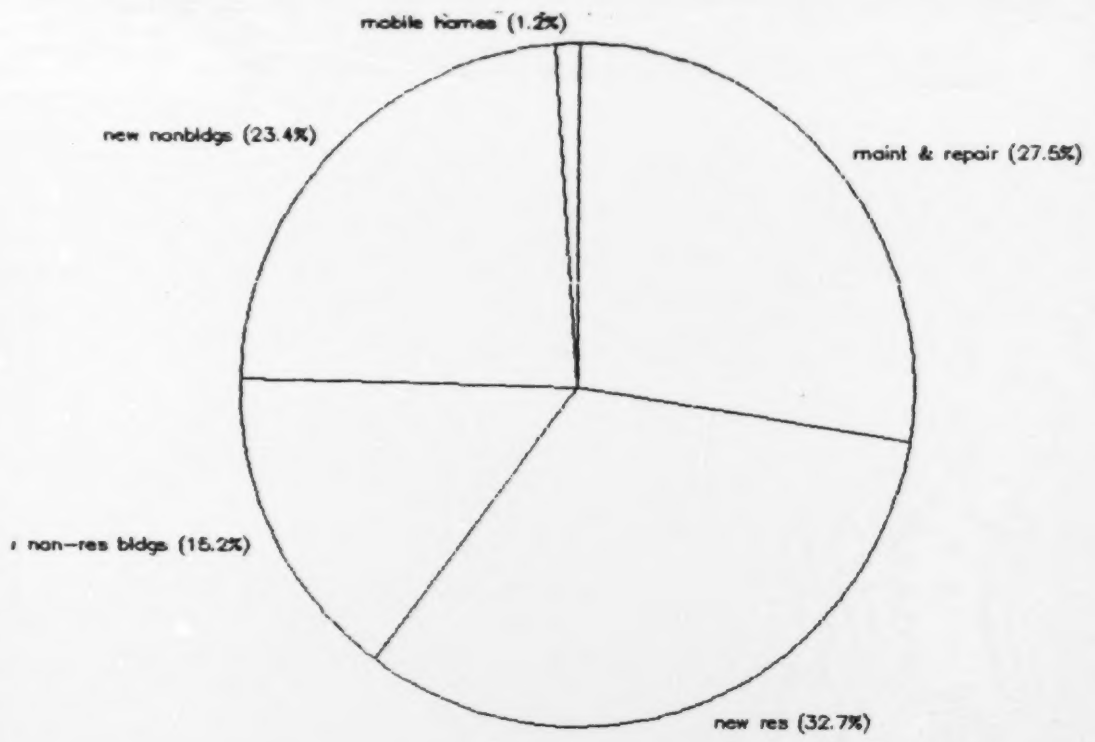

Figure 1. Distribution of 1977 U.S. Construction Output (Total = $266,630,600,000).

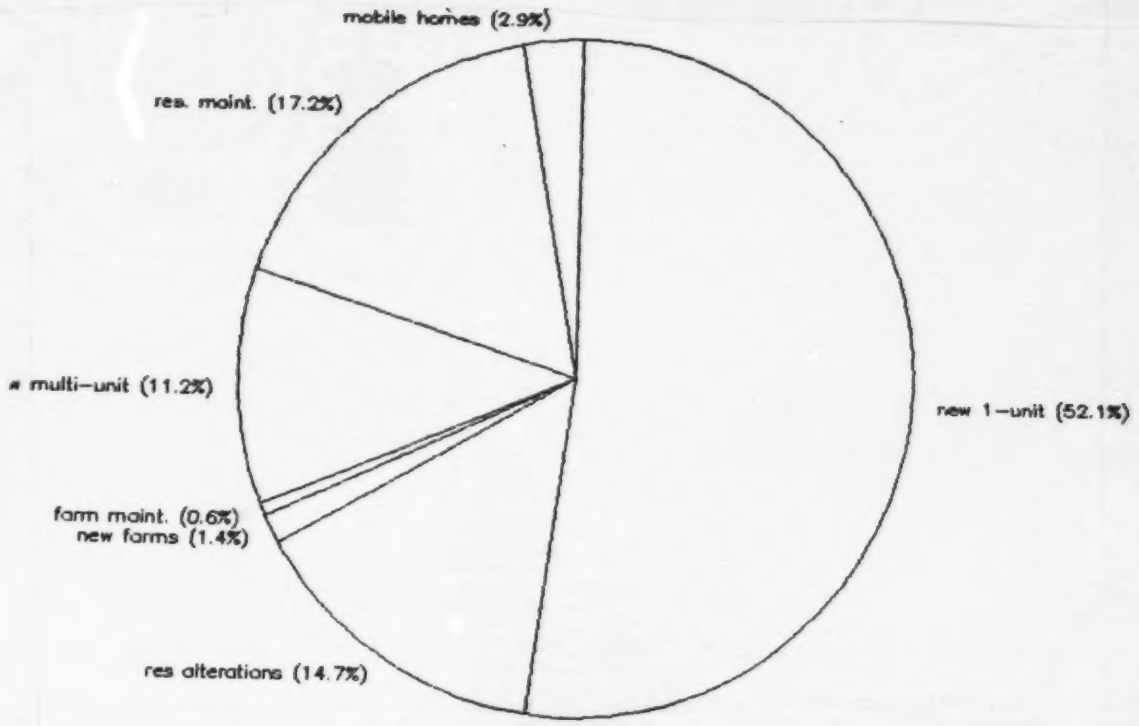

Figure 2. Distribution of 1977 U.S. Residential Construction Output (Total = $110,151,000,000).

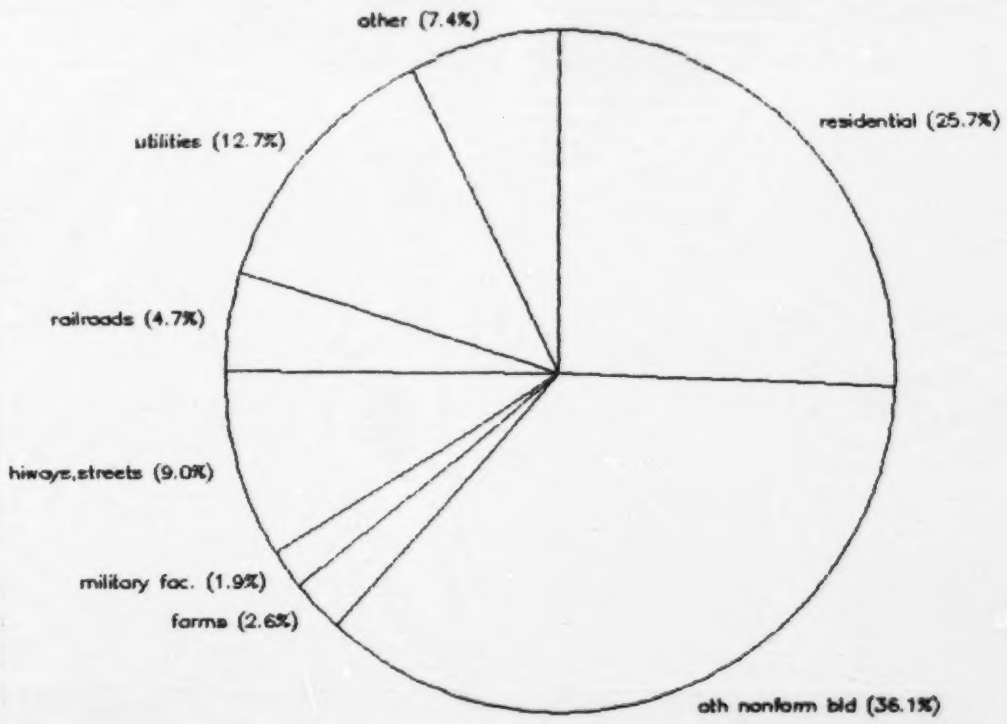

Figure 3. Distribution of 1977 Total U.S. Maintenance and Repair Output (Total = $73,639,600).

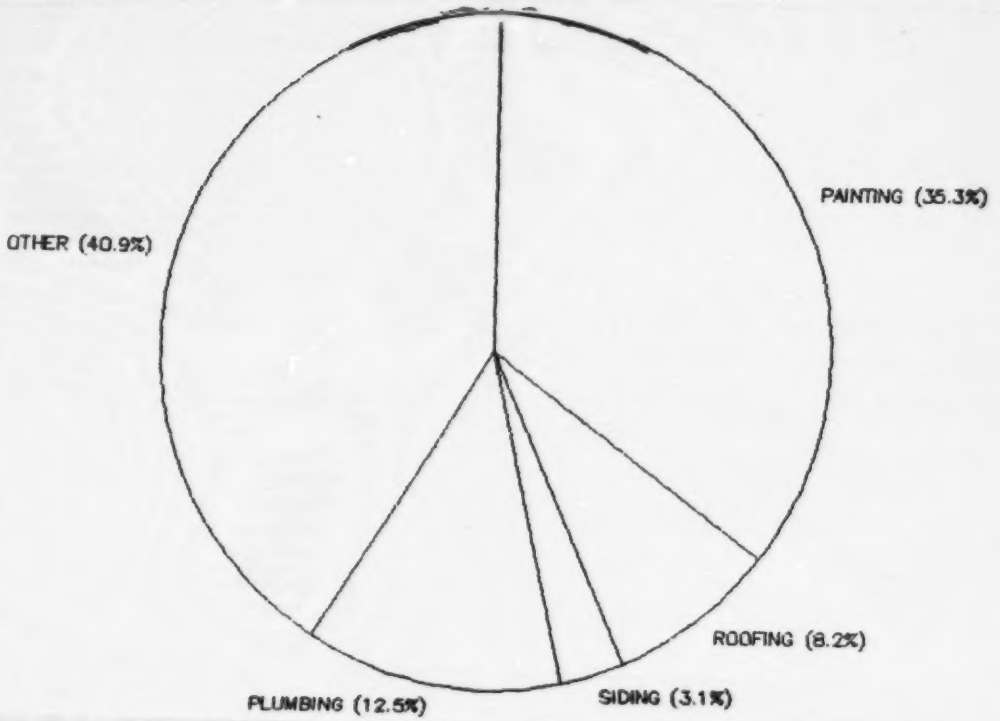

Figure 4. Distribution of 1977 Expenditures by Property Owners for Residential Maintenance and Repair.

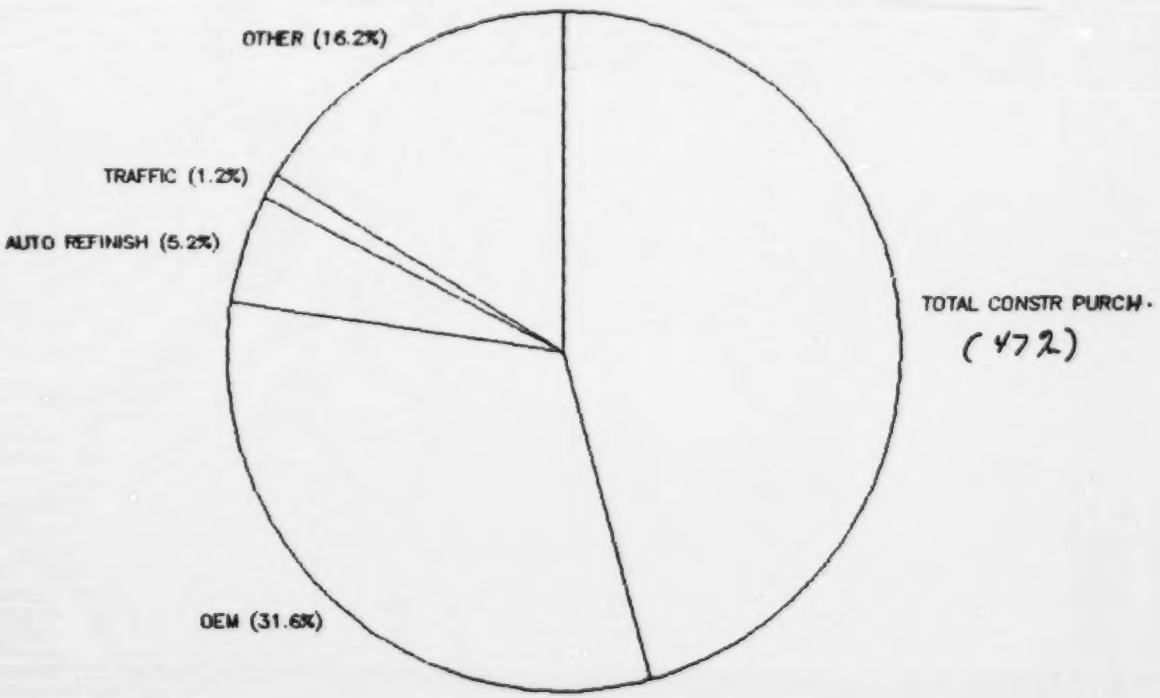

Figure 5. Distribution of 1977 U.S. Paint Sales (Total = $6.2 billion).

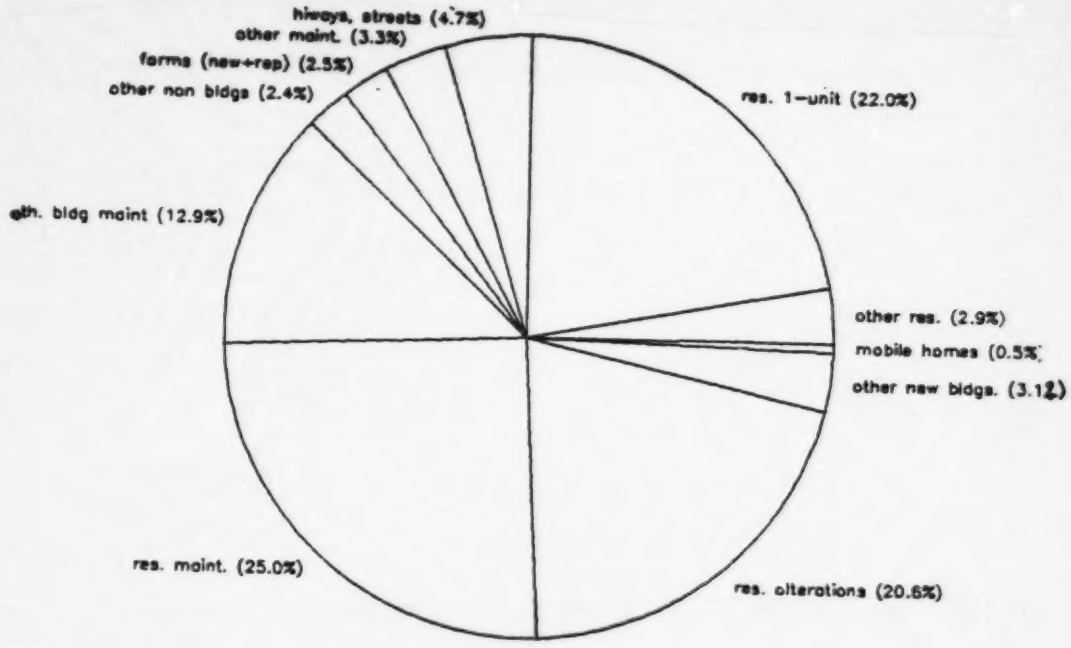

Figure 6. Distribution of 1977 U.S. Construction Paint Usage (Total = $2.8 billion).

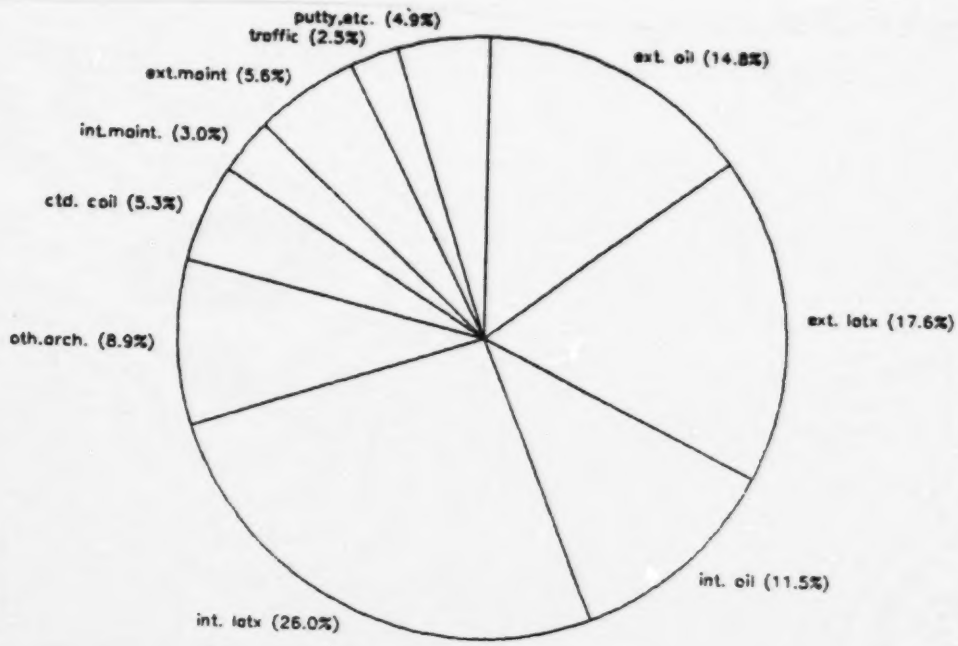

Figure 7. Distribution of 1977 Construction Paint Shipments (Total = $2.8 billion).

distribution of paint shipments is shown in Figure 7; about 40% of paint shipments were interior paints, but the split in in-place value would be tilted even more towards exterior paints because of their higher costs of surface preparation. The shorter replacement cycle of exterior paints follows from these data if one considers that there may be about three times as much interior as exterior surface area on a given building and that only about 25% of US housing units have wood exterior walls. However, a much higher percentage of single family houses have at least some wood trim.

Figure 8 gives a breakdown of construction industry purchases of materials that may be sensitive to acid deposition. Paints account for over half of these materials (but some portion is used indoors) and together with metal buildings (which are usually painted), over 80%. This reinforces our previous notions that in the U.S., painted surfaces tend to be the most abundant of those potentially sensitive to acid deposition.

The Census report "Residential Alterations and Repairs") is another source of data on painting costs; it places the total expenditure for 1977 residential maintenance by property owners at about $11 billion, of which out-of-pocket painting costs were about $4 billion. If the true value of "do-it-yourself" labor were included, the painting expense would be much higher. Combining the residential paint maintenance costs from the input/output (I/O) profile allows estimates to be made of the labor components, provided the retail paint markup (m/u) and the split between contract and do-it-yourself labor can be estimated. Figures 9a and 9b present these results. In Figure 9a the contractors' average charges per gallon of applied paint are estimated. A range of $60-80 per gallon seems reasonable for that time period, which corresponds to about 60-80% do-it-yourself labor. The corresponding multipliers for the "Residential Alterations" report are from 2 to 3 (Figure 9b). The fraction of do-it-yourself labor for exterior painting has been estimated from surveys (discussed below) at 65%; it is undoubtedly higher for interior painting. One indicator is the cost distribution data shown in Figure 10, also taken from the "Residential Alterations" report. The cost of contracted painting labor (and accompanying materials) was 36% in 1977; although the small jobs (< $25) were not broken down, it seems safe to assume that these constitute materials costs only. Multiplying by 5 to account for labor costs gives a split of about 9:1 for do-it-yourself:contract labor, with a total 1977 residential painting cost of about $14 billion. A further check on these figures may be obtained by considering the estimated output of the approximately 520,000 professional painters employed in the U.S. (Burkhardt, 1988). If we assume that they apply 25% of the residential maintenance paints and do all of the industrial maintenance and new construction painting, we arrive at an annual figure of 712 gallons per painter (a figure which is much higher than obtained by the painters at Brookhaven National Laboratory, for example), or about 1600 annual man-hours each, using the labor rate given by Means (1985). These seem to be reasonable estimates.

By 1986, residential painting expenses reported by property owners had risen to $11 billion. Using the multipliers developed above to account for do-it-yourself labor would increase this figure to the range $20-30 billion, in accordance with the data of Table 1.

The Census Bureau reports on characteristics of new housing can provide data on residential construction trends. For example, nationwide, use of brick is decreasing, aluminum siding and wood are about constant, and uses of stucco and other materials (such as vinyl siding) are increasing. Wood use tends to be proportionately more common outside Standard Metropolitan Statistical Areas (SMSAs) and the aluminum siding share, smaller. By region, we see the following percentage shares and trends:

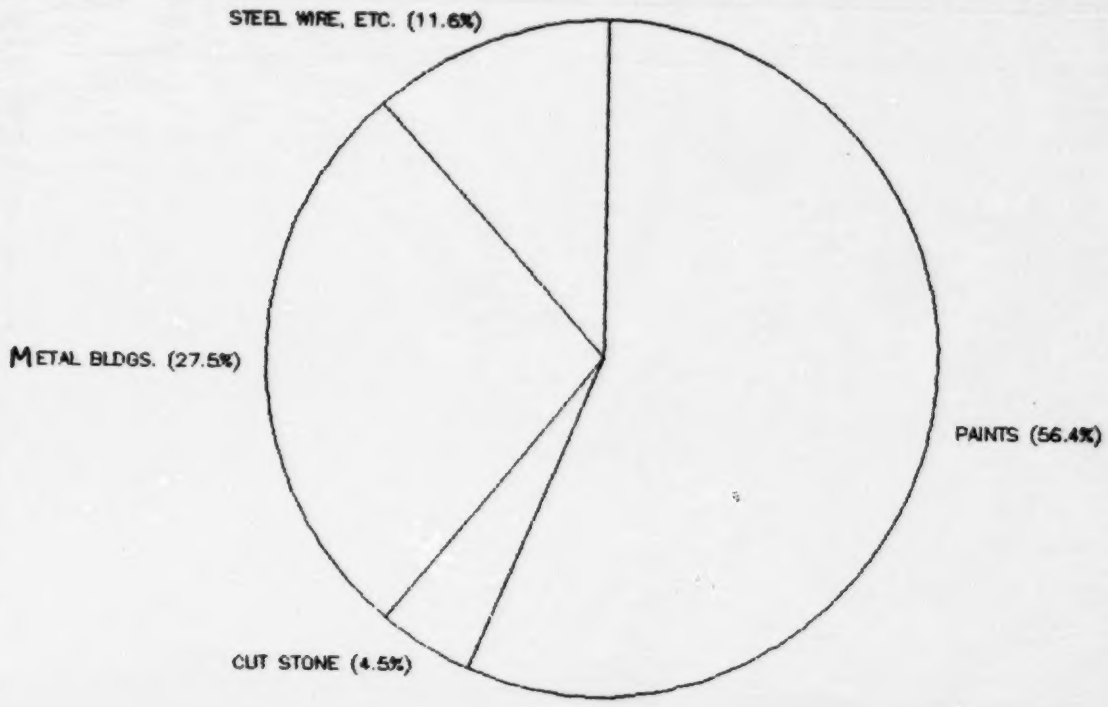

Figure 8. Distribution of Acid-Sensitive Materials Purchased by the Construction Industry (1977).

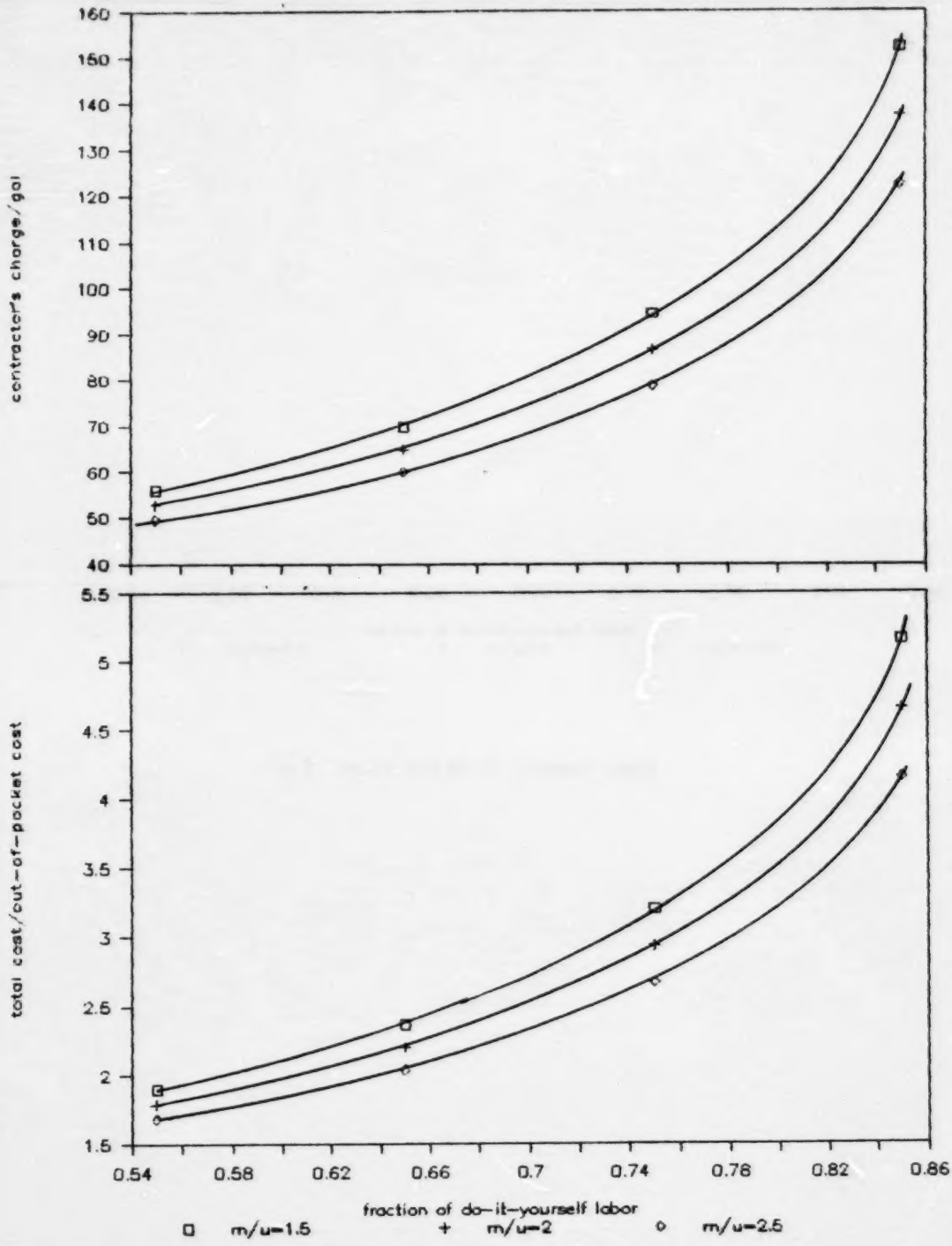

Figure 9. Estimates of 1977 Painting Costs. (a) Contractor costs for repainting. (b) Multiplying factor for do-it-yourself labor.

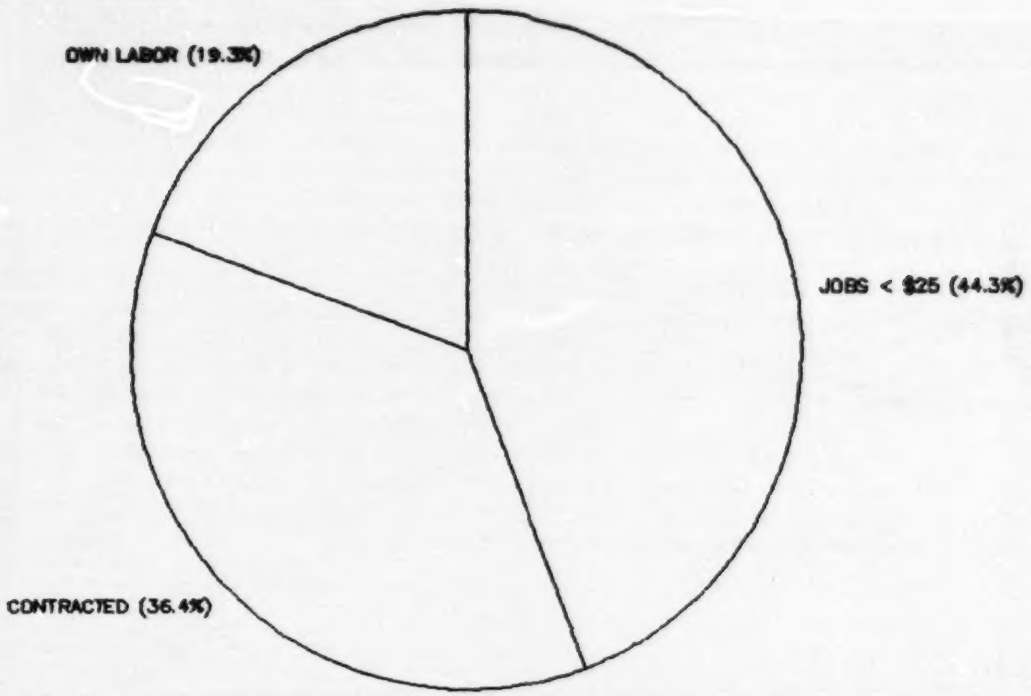

Figure 10. Distribution of 1977 Residential Painting Costs (Total out-of-pocket costs = $4 billion).

Region	Wood Share	Aluminum Siding Share
Northeast	50 (constant)	20 (decreasing)
North Central	55 (decreasing)	15 (constant)
South	35 (constant)	7 (constant)
West	44 (decreasing)	3.5 (constant)

Finally, a further comparison of new construction may be obtained by considering the shipments of coil-coated steel for various types of buildings, which totaled about 0.32 million tons in 1987. Assuming this material was of 26 gauge thickness, it would amount to 825 million square feet. This figure may be compared to the surface area of the 460,000 new single-family housing units which were built in 1987 with wood exterior walls, which, at 2000 square feet each, would amount to 920 million square feet, a comparable figure. Thus in terms of the exposed surface area of new construction, metal buildings and roofing are a significant component (even if not all the coated steel is exposed to the outdoors).

Another consideration with respect to research on paint performance is the substrate over which paints are applied (Williams, 1986). We indicated above that painted metal surfaces are becoming more important. Consumer surveys (discussed in Section 3) indicate that painted masonry is relatively unimportant. Pre-finished wood siding, which includes painted hardboard, was indicated above not to be very important in terms of total paint sales, but is becoming an important segment of the new construction market. Marcin (1989) indicates that the approximately 40% of new construction in 1987 with wood exterior walls included 15% plywood (primarily unfinished), 10% hardboard (primed), 7-8% solid wood, and 2% shingles. Since some portion of the solid wood siding is likely to be applied unfinished or stained, plywood and hardboard are seen to be important substrates in terms of conventional paints.

TRENDS IN PAINT USAGE

Since any environmental improvements achieved from controls on acid deposition and its precursors may not be realized until the next century, it is important to understand those trends in materials usage which could affect research priorities. Figure 11 gives the 1987 distribution of shipments of paints of various types. Comparison with earlier data indicates that oil-based architectural paints have decreased in relative importance in favor of water-based paints. According to Connolly et al. (1984), this confirms a trend that began in 1955. The automotive (and machinery) refinishing share has grown considerably, while coil coatings and maintenance paints have fluctuated, with no clear trend in relative shares.

The trends in absolute quantities of paint shipments are shown in Figure 12, based on two sources; The Census of Manufactures and a report by SRI International and Chemical Marketing Services, Inc. (Connolly et al., 1984), for the National Paints and Coatings Association, Inc. The differences shown on the figure between the two data sources are indicative of the uncertainties in this type of data. Figure 12 clearly shows the effects of the 1982 recession, and that the major growth since then has been in architectural coatings. Note that Figures 11 and 12 deal only with volumes of paints shipped, not with in-place values.

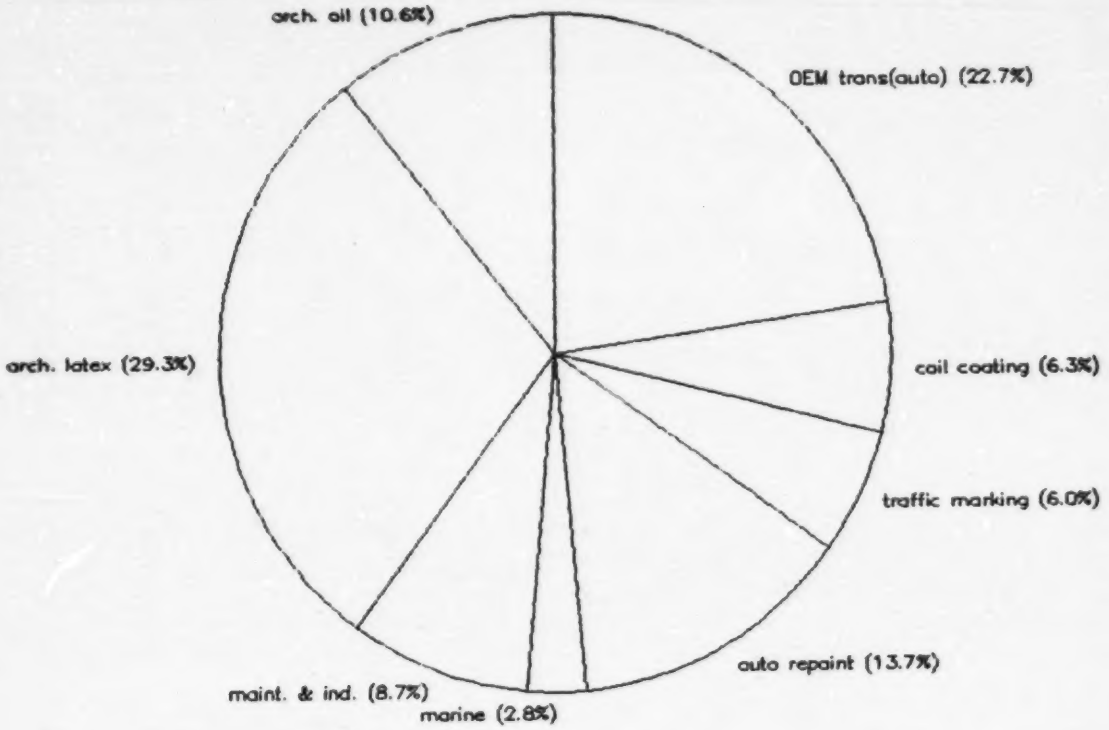

Figure 11. Distribution of 1987 Exterior Paint Shipments (volume).

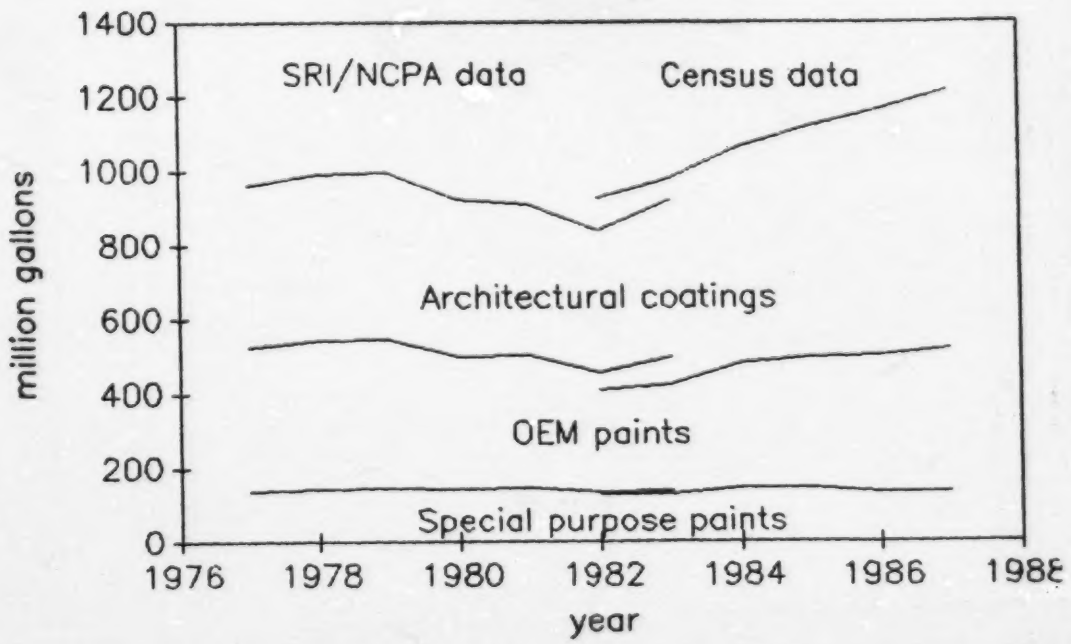

Figure 12. Trends in Paint Shipments.

Regional Distributions

In addition to temporal trends, it is important to determine spatial trends, particularly with regard to those portion of the U.S. that experience acid deposition. Some of the Census data on paint shipments are available by Census Division and Region. The four Census Regions are shown on Figure 13, which also depicts the average distribution of precipitation acidity from 1980-84. We see that the Northeast Region has a range of pH from 4.2 to 4.6, with most of the region less than 4.4. The North Central Region includes values from 4.2 to 4.8 and higher, with the most highly populated parts of the region below about 4.4. In the South, pH values are generally above 4.3, with most of the region above 4.5. pH values in the West are not shown, but they are believed to be above 4.6 or so everywhere except Southern California, where values may be slightly lower. However, in the parts of the West with lower amounts of rainfall, dry deposition of acidity may a more important indicator. Annual mean sulfur dioxide concentrations, for example, generally resemble the pH distributions in the Eastern US and the only division with substantially lower values is the West South-Central (Barchet, undated).

The Census of Manufactures provides paint shipment data by class and state or Census division. Since in 1977 the average paint shipment distance was about 330 miles and the median, less than 200 miles (Rauch, 1985), we assumed that most of the paint produced in a Census Division was consumed there. This assumption may be tenuous for the smaller divisions, such as New England. Figure 14 plots exterior paint shipments by division versus the numbers of single-family housing units with wood exterior walls, which were assumed to be constant over time, using data as determined by the DOE Residential Energy Consumption Study (as presented by Lipfert et al., 1986). The slopes of the lines represent annual gallons per house, which were determined by linear regression, forced through the origin. Note that this analysis does not allow for exterior paint usage on multi-family or nonresidential buildings, which will inflate the apparent usage by single-family residences. The average slope values obtained were:

1972, oil-based	4.36/gal/house
1972, latex	4.33 gal/house
1982, total exterior	7.62 gal/house

By comparing the data points with the regression lines, we may determine whether usage in a given region is higher or lower than "expected." The Census Divisions (locations shown on the inset map of Figure 14) with above average shipments and presumed consumption were:

1972: East North Central (ENC), Mid-Atlantic (MA)
1982: East North Central (ENC), Pacific (PAC).

While Figure 14 may relate more to the locations of paint manufacturing than to any other factor, it is also possible to speculate that the East North Central Division produces and consumes relatively more exterior architectural paint in part because of its more severe environment (including air pollution). It is also of interest to note that the average apparent paint usage per house has decreased since 1972, by about 14%. (Temporal trends in usage for individual Census Divisions may be seen from the relative positions on the plot). This could be a result of better paints, deferred maintenance and construction of smaller new houses because of economic conditions in 1982, or longer lifetimes of the paint systems (a part of which could be due to the reduced air pollution that has occurred in many cities since 1972).

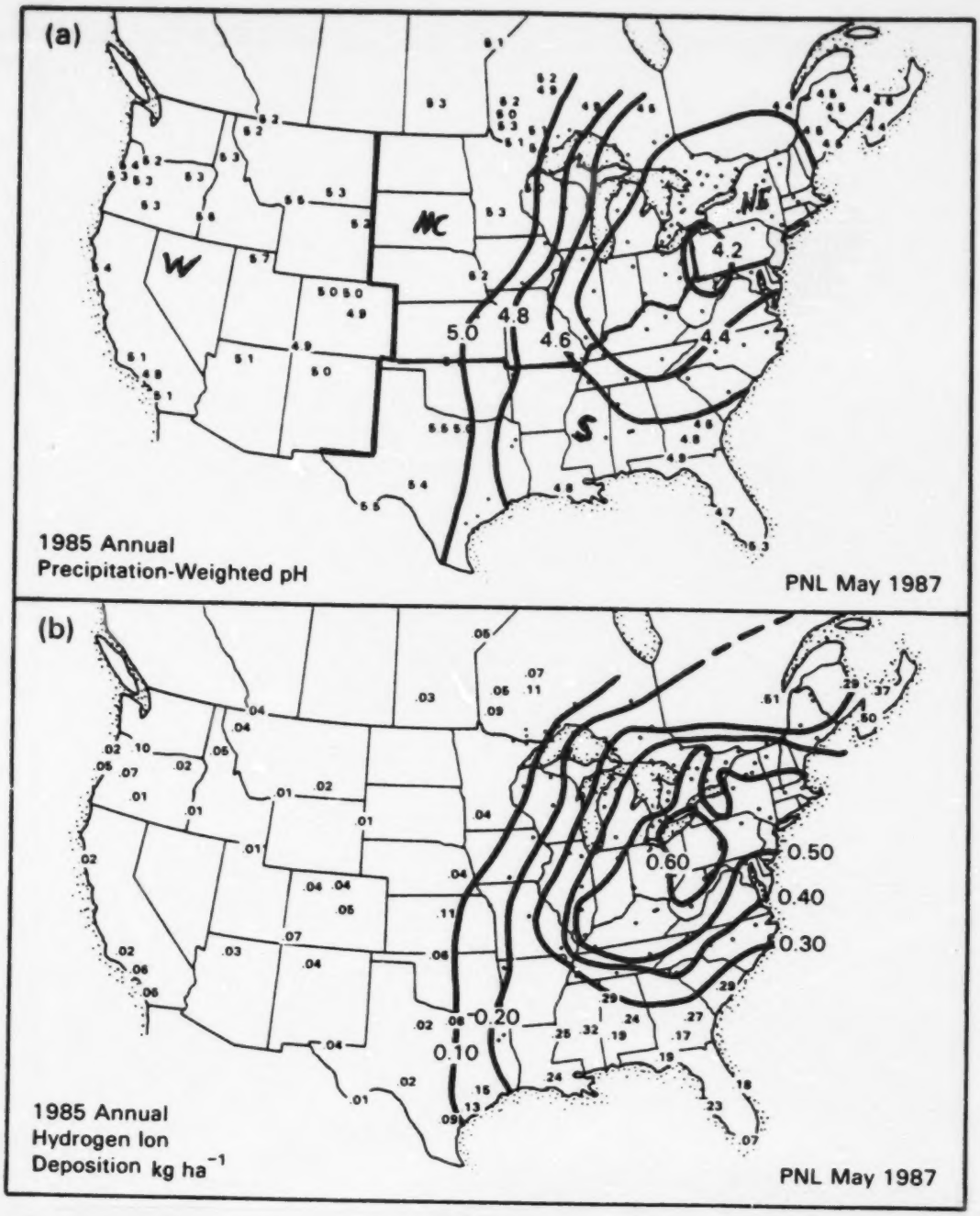

Figure 13. The 1985 Annual distribution of (a) precipitation-weighted pH and (b) H^+ deposition. Source: NAPAP.

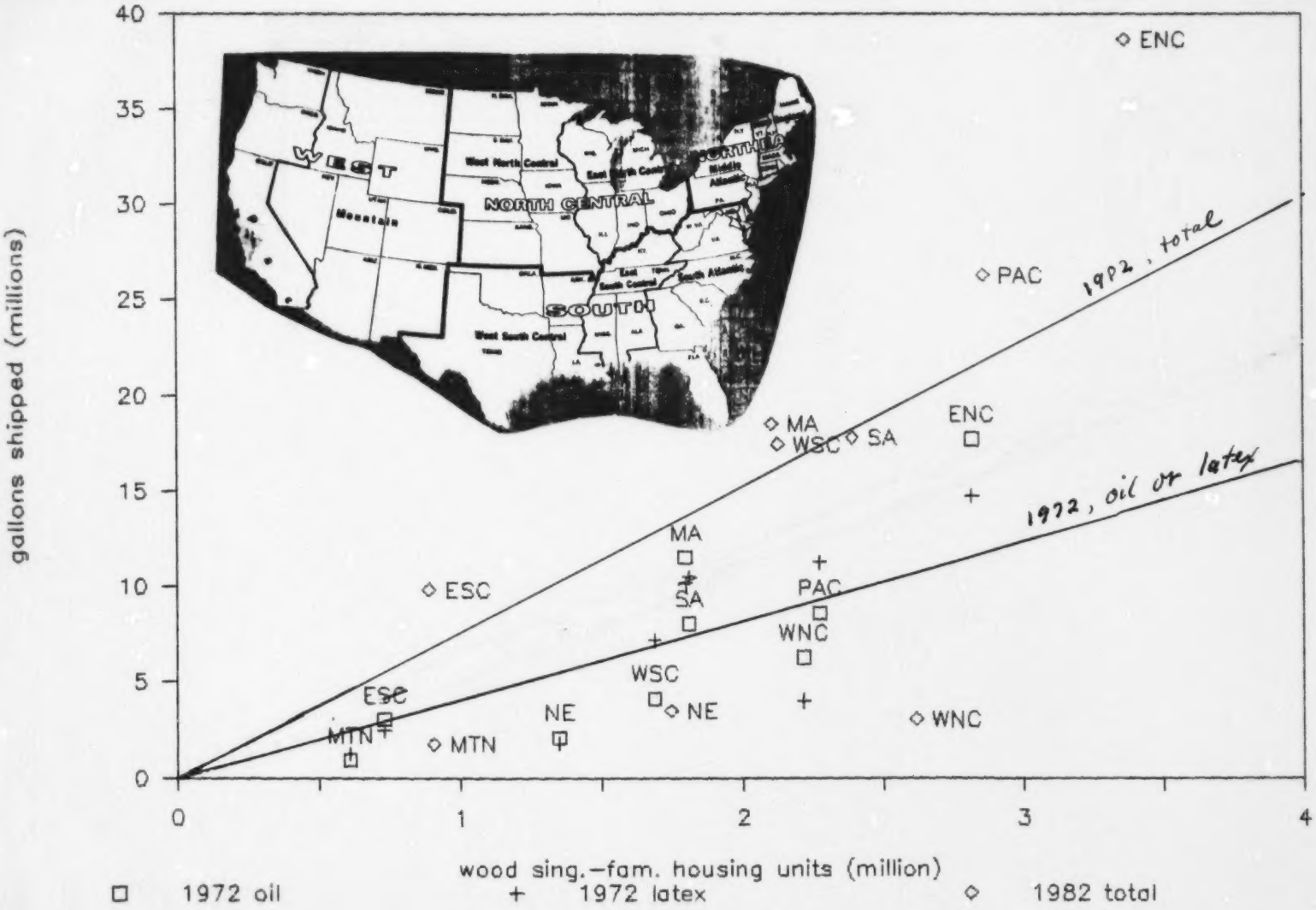

Figure 14. Exterior Architectural Paint Shipments by Census Division.

ENVIRONMENTALLY SENSITIVE COMPONENTS IN PAINTS

Of the main functional components in paints, the characteristics of the polymers and the pigments are the most important with respect to the effects of the environment on the paint system. The characteristics of the solvents are important to the environment primarily from a different perspective: their contributions to air pollution as they evaporate. To the extent that paint formulations change in response to hydrocarbon emission limitations. there may be some interactions between these two types of environmental considerations.

Pigments and Extenders

As mentioned above, laboratory and field experiments have identified two components of commonly used paints that respond readily to leaching by acidic deposition: ZnO and $CaCO_3$. Zinc oxide is used as a pigment and also to make certain mildewcides more effective (Carder, 1989) Of the two, the leaching of $CaCO_3$ is probably the more serious since it tends to be used in larger proportions. Its purpose is to provide body and pigmentation at low cost. It is also used in a very finely ground state in glossy paints, since the extra thickness helps smooth tiny surface imperfections, which improves the gloss. $CaCO_3$ is also heavily used in "chalking" paints (in addition to anatase TiO_2).

The general opinion in the paint industry seems to be that use of $CaCO_3$ as an extender is a mark of the cheaper trade sales or "contractor" paints and that this practice has diminished over time. Table 2 presents data from 1973 to 1983 (Connolly et al., 1984) that show only a very slight decrease in the average CaCo3 content and these small changes may well be due to shifts in the relative amounts of different types of paint, rather than changes in the composition of each major type. In addition, a recent ad hoc survey of paints available from local retail outlets found paints selling for up to $28 per gallon containing appreciable $CaCO_3$;. Table 3 presents the results of this survey. Several of the national brand paints are now being sold unlabeled, as well as "house" brands from local discount outlets. In addition, Mosely's analysis (1983) indicates that the composition data shown on paint labels are not always reliable.

Connolly et al. (1984) present a matrix of paint ingredients by type of paint product that provides insight into the usage of acid-sensitive ingredients. For example, ZnO is used mainly in exterior architectural coatings, with an average content 0.6% in flat exterior latex and 6% in oil-based exterior flat paint. Table 4 presents the distribution of usage of $CaCO_3$; the largest single usage is for traffic paints, although the sum of all architectural coatings accounts for more. In terms of average composition, traffic paints contain an average of 23% $CaCO_3$ and all other categories average much lower. Maintenance paints and coil coatings appear to contain negligible amounts of $CaCO_3$, for example. Assuming that when an architectural coating contains calcium carbonate, the composition is about 30% by weight, then about 18 - 19% of total architectural exterior paints would be affected. Of the detailed types of architectural coatings for which $CaCO_3$ data are given, relatively large average proportions are in oil-based primers (14%) and interior oil-based flat paint (22%). Although our retail survey tended to find calcium carbonate in glossy oil-based exterior paints (according to the labels), this tendency is not borne out by the data of Connolly et al.

Although rutile titanium dioxide is the white pigment of choice in most cases, the paint industry has been suffering from a shortage of manufacturing capacity (Chemical Week, 1988). Recently announced facility additions should help relieve this situation.

Table 2. Trends in Usage of Acid-Sensitive Paint Components (10^6 lbs)

year	TiO_2	ZnO	$CaCO_3$	total av'g arch. paint*	$CaCO_3$ content %
1973	864	52	400	3830 (est.)	10.4 (est)
1974	791	34	405		
1975	711	25	385		
1976	787	28	395		
1977	804	29	405	4370	9.3
1978	822	30	415	4480	9.3
1979	835	30	420	4500	9.3
1980	780	28	385	4240	9.1
1981	760	28	380	4070	9.3
1982	695	25	355	3830	9.3
1983	780	27	378	4220	9.0

* @ 10 lb/gal
Data from Connolly et al. (1984)

Table 3 Local Retail Paint Survey Findings

Brand	Price/gal	Ingredients
Pittsburgh House and Trim Paint Pittsburgh Black Latex Flat	$27.89	18.2% $CaCO_3$ iron oxides
Truetest House and Trim Paint	19.98	6.5% $CaCO_3$
Truetest Accent Color Brown Latex	19.98	iron oxides
Weatherall White Latex	17.98	TiO_2
Rickel One Paint Gloss Latex	11.99	TiO_2
Moore's House Paint (High Gloss)	24.98	13.5% $CaCO_3$
Mooregard Latex	21.95	
Moore's Flat Latex Masonry and House Paint		TiO_2, ZnO
Mooreglo White Latex House & Trim Paint		TiO_2, ZnO
Glidden Spred White Latex Flat	12.99	TiO_2, ZnO
Glidden Spred Green Latex Flat	12.99	iron oxide
Glidden Spred Red Latex Flat	12.99	iron oxide
Glidden Spred Oil Base Primer	12.99	TiO_2
Dutch Boy White Oil Base Gloss	21.99	TiO_2
Dutch Boy White Latex Gloss	9.99	TiO_2
Pratt & Lambert Latex Satin		TiO_2, iron oxides

Table 4 Distribution of Calcium Carbonate in Paints

paint type	1982 product (million lbs.)	1982 $CaCO_3$	1982 %	1983 product (million lbs.)	1983 $CaCO_3$	1983 %
Interior Latex	1859	52.6	2.8	2020	57.1	2.8
Interior Solvent	414	35.7	8.8	450	37.4	8.3
Exterior Latex	1107	72.6	6.5	1295	85.0	6.6
Exterior Solvent	616	23.	3.7	658	27.8	4.2
Factory Wood	137	7.1	5.2	166	8.0	4.8
Coil Coating	177	2.3	1.3	201	2.6	1.3
Maintenance Paint	263	0.9	0.3	247	0.8	0.3
Traffic Paint	492	115.1	23.4	492	115.	23.
Other Special Purpose Paint	271	30.7	11.3	292	33.4	11.4

Data from Connolly et al. (1984)

Polymers (Resins)

A detailed discussion of polymer characteristics is beyond the scope of this report. In general, the polymer for a given paint application is selected to give the desired physical and weathering properties of the coating, in addition to economic considerations. Among the most important properties is the degree of cross-linking between the monomers comprising the polymer. These linkages can be affected by weathering over time, for example by exposure to ultraviolet radiation and photochemical oxidants.

The main resin classifications are:

- polyesters
  - alkyds w/ vegetable oils
  - oil-free polyesters
  - siliconized polyesters
- acrylics
  - water-based emulsions
  - thermoplastic solvent-based
  - thermosetting solvent-based
- vinyls
  - water-based
  - solvent-based
  - dispersed (plastisols)
- epoxies
- urethanes
- others (includes cellulosic, phenolic, amino, chlorinated rubber, natural resins, fluorocarbons).

Polyesters include the alkyds based on vegetable oils such as linseed oil. These are used in house paints and light duty maintenance paints and generally represent low-cost applications. According to Kaminski (1987), in the nonresidential applications, 35% of alkyds are used for industrial maintenance, 44% for commercial buildings, and 21% for institutional buildings. Water-based acrylic resins are the main polymer for latex house paints, in addition to water-based vinyls. Acrylics are also used in various forms in product finishes. According to Connolly et al. (1984), the vinyls are noted for their chemical and water resistance in addition to durability and low cost. Epoxies, urethanes, and fluorocarbons are examples of resins that provide better protection, at higher cost. According to Metal Building Review (1986), use of 70% polyvinylidene fluoride polymer for coil coatings (Trade name "Kynar-500") can extend coating performance from five to twenty years, at an applied cost increase of about 150%. In order to be able to detect environmental degradation in a reasonable length of time, the lower cost formulations, such as alkyds, represent preferred candidates for initial research on the effects of acidic deposition.

Table 5 presents the distribution of resins by (outdoor) application, ca. 1983 (data from Connolly et al., 1984). The table shows that some paint applications are dominated by specific resins, whereas factory-applied finishes and maintenance paints are more diversified. Many of these resins were developed to meet specific needs and thus tend to be limited to those applications.

Table 5. 1983 Distribution of Resins in Paint and Coatings (percent)

Paint Type	Alkyd	Lins.Oil	Acrylic		Vinyl			epoxy		Urethane	Polyester	Other
			water	t/p sol	t/s sol	water	solv.	dispers.	ester	reactive			
Exterior, Water			67.9		28.5						3.6	
Exterior, Solv.	56.9	29.4										
Transpt. Equip (new)	19.5		2.3	12.6	15	0.9		3.9	13.7	6.1	2.7	23.3
Auto Refinish	42.5			33.1				1.4		9.6	1.4	12.0
Wood Flat Stock	24.1		28.0	4.5	14.2	3.5				5.3	3.5	16.9
Coil Coatings	9.4		10.1	1.6	18.1	3.1	6.2		11.7	3.1	18.9	17.8
Industrial Maint.				3.9		12.2		2.7	31.3	18.9	4.4	26.6
Traffic Paints	80.4								0.7		2.7	16.2

Data Source: Connolly et al. (1984)

SECTION 3

CHARACTERIZATION OF FAILURE MODES

There are many ways for a paint system to fail. Broad mechanistic classifications include separation of the film from the substrate and deterioration of the film per se. Allowing moisture or air pollution to penetrate the film may lead to some degradation of the substrate which then promotes delamination. From the consumer's perspective, a number of types of paint defects have been identified, including peeling, cracking/checking, fading or discoloration, loss of gloss, chalking, and erosion. Accumulation of dirt or mildew may relate more to the environmental conditions than to the paint. The ideal failure mode is probably erosion, in which the film maintains its appearance and integrity until it is worn away by rain or other weather factors. Examples of 100-year old paint remnants which may have performed in this manner can be seen in ghost towns in the arid Western US. An example of severe paint peeling is shown in Figure 15.

MEASUREMENT AND EVALUATION OF PAINT FILM DAMAGE

The American Society for Testing and Materials (ASTM) has developed standardized methods, as published in Vol. 6.01 of the Annual Book of ASTM Standards. A glossary of paint defect terms is given in Appendix A to this report; many of these measures are evaluated visually using arbitrary ratings from 1 to 10. In addition, manufacturers often have their own systems.

For lack of a better metric, the loss in weight of a painted test coupon has been used in environmental tests and described as a measure of erosion. During the early portions of an exposure period, such losses in weight may be due to loss of the volatile components of the film. In addition, oxidation of a paint film may result in a slight weight gain. These changes in film weight due to "natural weathering" may confound attempts to determine the weight changes that resulted from air pollution or acidic deposition.

PROFESSIONAL PAINT TESTING AND EVALUATION

Paint manufacturers and occasionally other testing organizations evaluate the performance of paints on a relative basis. Small specimens or coupons are placed on racks or "test fences" at various locations and then evaluated at periodic intervals, usually on a somewhat subjective basis. Although differences in relative paint durability can be seen in this way, these systems do not encompass many of the problems encountered by property owners, such as previously painted surfaces, moisture in the system, expansion and contraction of larger surfaces. As a result, professionally-tested paint lifetimes tend to be long, seven years or more, and catastrophic peeling failures are relatively rare.

Union Carbide Test Panels

Starr (1986) reports on a seven year exposure program at three locations (New Jersey, Illinois, and Texas), by the UCAR Emulsions Systems Division of Union Carbide. The substrates were either western red cedar or white pine, three different primers were used, three

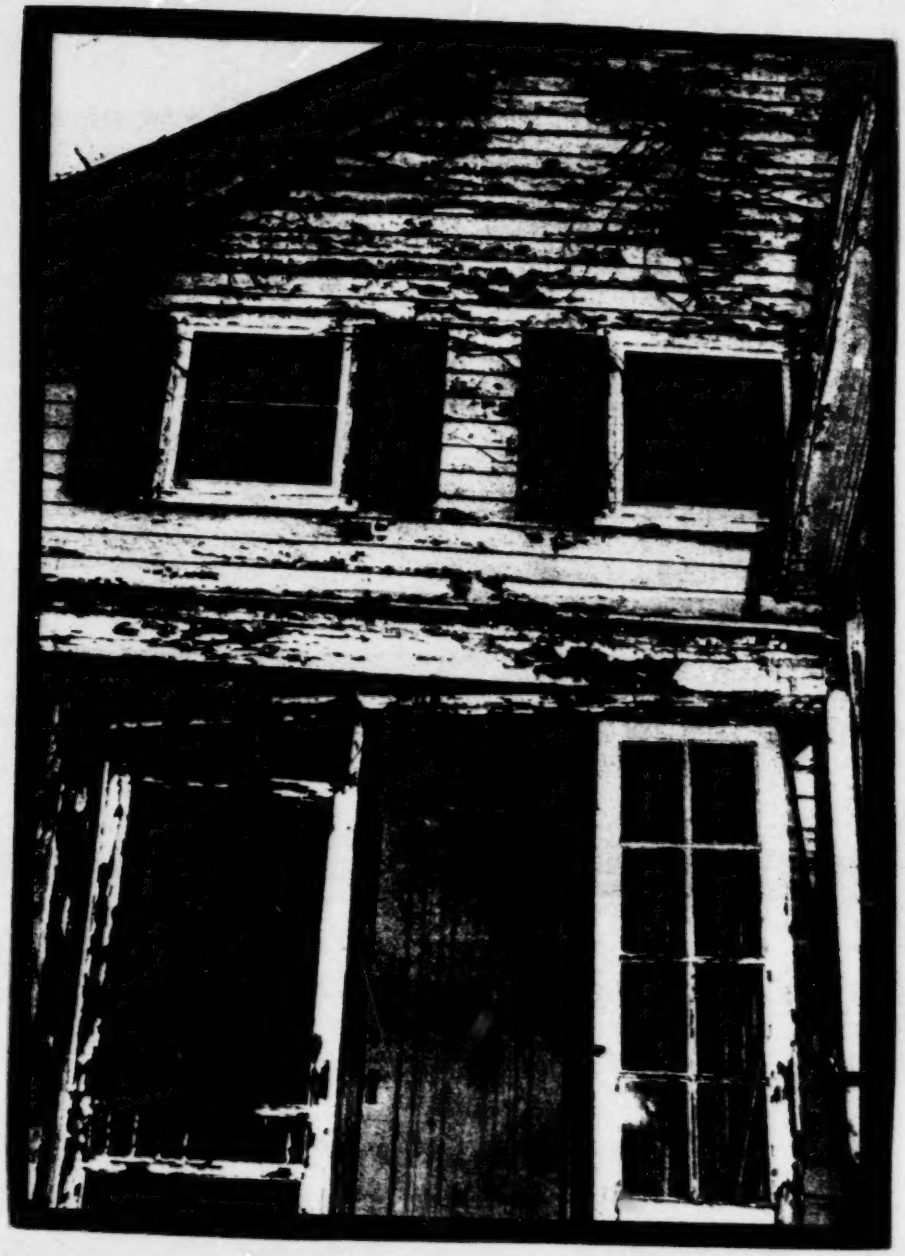

Figure 15. Example of Severe Paint Peeling.

different mildewcides, vertical positions facing either south or north, and six different formulations of acrylic latex exterior house paint, applied by brush with two topcoats. In general, these paints performed well; there were no peeling failures. Mildew was a problem in Texas. Based on ratings for cracking, checking, chalking and fading, there were essentially no differences among the three test sites. Fading was the most common problem at all three sites. No information was provided on the composition of the paints.

EPA Tests at St. Louis

The U.S. Environmental Protection Agency conducted a 30-month test program of both latex and oil-based house paints at nine locations in and around St. Louis, using weight loss as a damage measure. Although the original report (Haynie and Spence, 1983), which did not consider the effects of rain, found no effects due to SO_2 air concentrations, subsequent analysis using SO_2 deposition data provided by Haynie implies an SO_2 effect on the latex paint, in addition to ozone and rain amount. Figure 16 presents the latex paint weight loss data, adjusted for ozone and rain, plotted as a function of SO_2 deposition. Dropping the first three months, during which weight loss might be most influenced by loss of volatile components, clarified these relationships. For the oil-based paint, this reanalysis indicated smaller ozone effects, larger rain effects, and no SO_2 effect.

Consumers Union Paint Tests

In June 1987 Consumer Reports published results of one year exposures of 28 latex and 14 oil-base paints and stains at three locations: Mt. Vernon, NY; Miami, FL; and Brownsville, TX. The paints included both colors and whites as well as special mildew-resistant formulations. The paints were applied with and without primers on two types of substrates. The exposed samples were evaluated subjectively for adhesion to chalk, hiding power, resistance to color change, erosion, mildew, and dirt accumulation. The published brand ratings were based on the worst performance for that particular paint among the various combinations of location, use of primer, type of substrate, and number of coats (one or two).

No peeling, cracking, or intercoat separations occurred during the one-year exposures. Since the brands were identified, we were able to compare performance with paint composition, as defined by the manufacturers' labels (not all of which included composition data). Only one of the latex flat house paints contained appreciable $CaCO_3$; it was judged poor in adhesion to chalk but superior in erosion resistance. Several of the oil-based glossy paints contained $CaCO_3$; some of these (but not all) were below average in erosion resistance. All of the oil-based paints adhered well to chalk. One latex-based stain contained $CaCO_3$; it did not perform appreciably worse than the others.

For the paints, dirt accumulation was the performance criterion showing the most deviations from an "excellent" rating, followed by fading. As might be expected, dirt ratings were the worst on the lighter colors. There was no obvious relationship between high chalking and low dirt, although this is one of the purported advantages of chalking paints. One brand of white latex, which was high in $CaCO_3$, was labeled "self-cleaning" white. Among the colors, the yellows and golds suffered most. Several "Southern" formulations containing additional mildew protection, were tested; their mildew performance was not appreciably better and they were more prone to chalking.

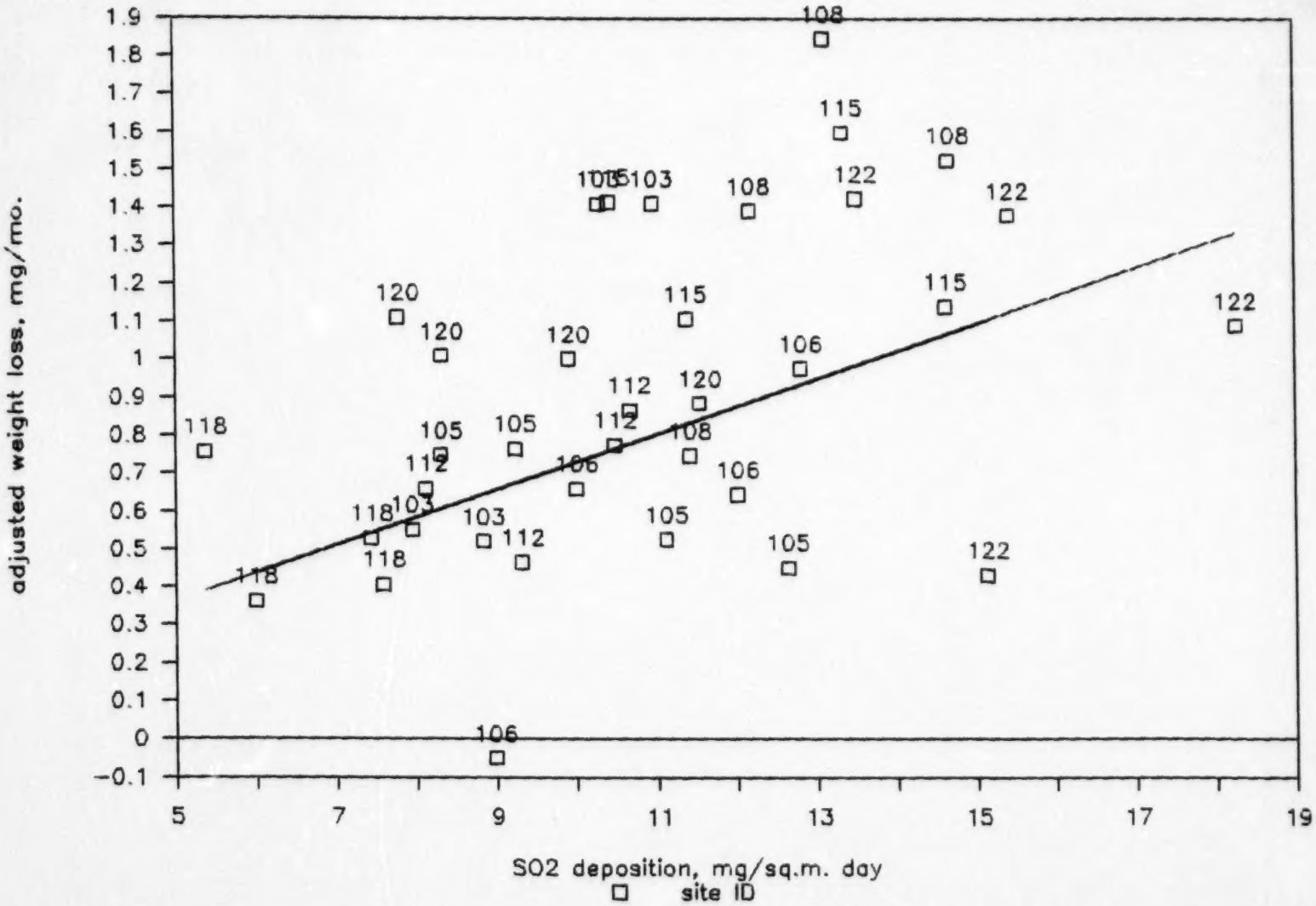

Figure 16. RAPS Latex Paint Weight Loss (first three months deleted).

PAINT EVALUATIONS BY PROPERTY OWNERS

The paint durability experiences of property owners are often in sharp contrast to those of the professional tests. Part of this dichotomy may be a result of faulty "do-it-yourself" paint application (such as failure to properly prepare the surface), but much of it must also be due to differences in the conditions of application. Although these experiences represent the "real world" of the most economically-important sector of the paint industry, our ability to obtain factual, unbiased information is often limited. There are survey data available, but as in all surveys, their applicability is limited to the population of survey responders, which may differ from the population of property painters as a whole. As usual, we rely on potentially compensating factors: 1. The populations sampled tend to be better educated and more economically advantaged than the population as a whole, and thus perhaps fewer failures might be expected because of access to better materials, advice, etc., and because of having the resources to perform maintenance as needed. 2. Within this population, those experiencing problems may be more likely to respond to surveys.

1975 Mail Survey

A large consumer organization polled its readership in 1975 with respect to residential exterior painting since 1970. The sample was over 200,000 in number, distributed nationally, but with higher incomes and more education than the national average. The section of the questionnaire on paint was completed by 41% of the sample, a higher proportion than the fraction of wood housing in the US. Although the questionnaire was not explicit, the implications were for repainting house walls, rather than just trim.

Of the responders, 76% painted wood and another 13% painted a combination of wood and masonry. 5% painted only masonry. The split between latex and oil-based paints was 73:27%; 26% of the respondents reported using a primer. The time elapsed since painting varied up to five years (the maximum allowed on the questionnaire), with a weighted average of 26 months. During this time, 52% of the respondents reported no problems; 28% reported peeling or flaking.

Figure 17 presents the distribution of reasons for repainting, with respect to their previous painting. Only 9% chose to repaint solely to change the color, 46% reported peeling of the previous paint, and 17% reported failure by erosion. Mildew and deterioration of the original color represented small fractions of the reasons for repainting.

A number of useful cross-tabulations were done with these survey results. The subset of wood houses painted in 1974 or earlier, without use of a primer but with identified types of present and previous paints, was used for an analysis of failures (about 29,000 cases). These cases were stratified by Census Region (n=4) and types of previous and present paint (latex over latex, oil over oil, and latex over oil). "No problems" were reported by about the same fraction of this subpopulation as by the total population, which included 26% who used a primer. Thus the benefits of priming appear to be small. Figure 18 displays these cross-tabulation results as a function of the number of years since repainting (it was assumed that no one would report problems at the time of repainting). On the basis of all paint types aggregated (Figure 18a), by region the West stood out as having better performance than the others; most of the "problems" seem to have appeared by the third year (over half of the subpopulation). The differences among paint types were not large when aggregated across regions (Figure 18b). Latex on oil did poorly in the North Central Region; oil on oil did

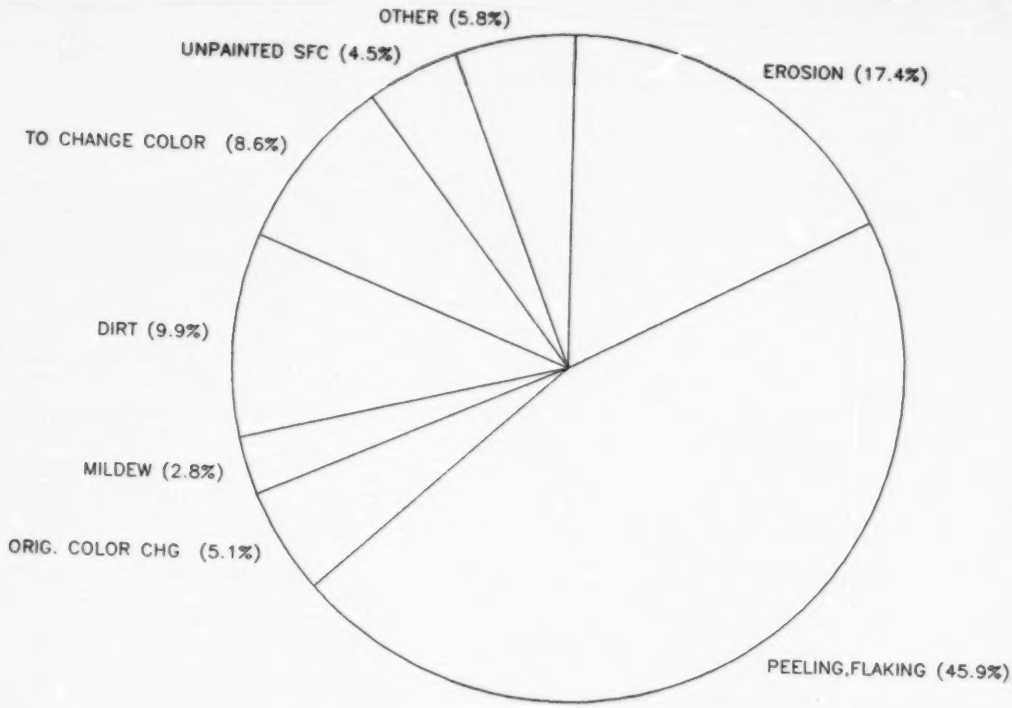

Figure 17. Distribution of Reasons for Repainting (1975 mail survey).

poorly in the South and West. In the Northeast, latex on oil did poorly after three years. Figure 19 shows the regional performance of latex applied over oil; the North Central Region performed the worst, with about 70% failures within three years.

Two types of failure modes were analyzed in detail: peeling or flaking, and mildew. Figure 20a presents the peeling data, aggregated across all paint types and without regard to previous peeling. We noticed that the four regions are in rough proportion to their sulfur air pollution levels (data for 1969-71 from Lipfert, 1978); the cross-plot is given as Figure 20b. With only four data points, this is a very speculative presentation, but the linear regressions through each time period suggest that peeling at higher pollution levels has a shorter induction period than at lower air pollution levels. The question of the mechanisms for this behavior and the responsible agent(s) remain topics for research. It would also be interesting to replot Figure 20 with air pollution data from each of the specific time periods during which repainting was done.

However, there are many other regional environmental differences to consider besides air pollution. Williams (1989) pointed out that the North Central Region, for example, suffers more from weather extremes because of its continental climate and that the winter ultra violet radiation exposure of a vertical wall may be higher than in more southern latitudes because of the low sun angles and reflection from snow covered ground surfaces.

In Figures 21 and 22, the data have been segregated according to the prior presence of peeling (after the previous painting), which is seen to have a major influence. The probability of peeling is increased by about a factor of three if peeling was previously present, in all regions and for all types of paint. The West region had the fewest peeling problems; the rankings of paint combinations varied. In the absence of previous peeling, latex on oil was usually the most likely to peel, especially in the North Central or Northeast Regions. With previous peeling, the difference were smaller but latex on latex was often the worst; perhaps a deteriorated oil-based paint surface provides better adhesion for repainting. The probabilities of peeling are compared for the present and previous paintings in Figure 23, based on aggregated data (rather than individual houses). The fractions of original peeling were deduced from the survey results and are higher in the North Central and South Regions, which is a change from the results of the subsequent paintings. Part of the difference may result from the fact that reports of peeling of the previous paintings had no time dimension, while the subsequent painting was evaluated after a maximum of five years. Figure 23 implies that in the South and West either peeling performance has changed since the previous painting or the asymptotic rate of peeling is being approached more slowly there. The shapes of the curves would appear to favor the first hypothesis.

The 1975 survey also dealt with mildew problems in terms of the previous existence of mildew, which was an overwhelming factor but far more common in the South. In the absence of previous mildew, the South had by far the most frequent problems, for all types of paint application. After about two years' exposure, time was not a factor. With previous mildew, there was a slight tendency for latex on oil to result in more frequent mildew in the South.

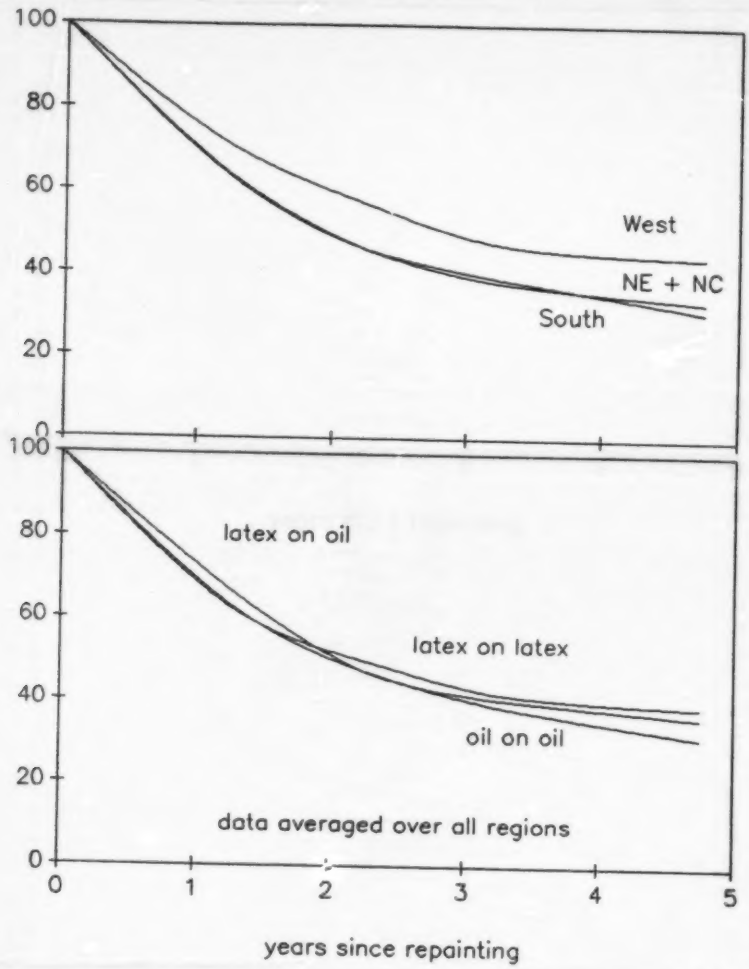

Figure 18. Percent of Respondents Without Problems (1975 mail survey). (a) all paint types, by region. (b) by paint type (all regions).

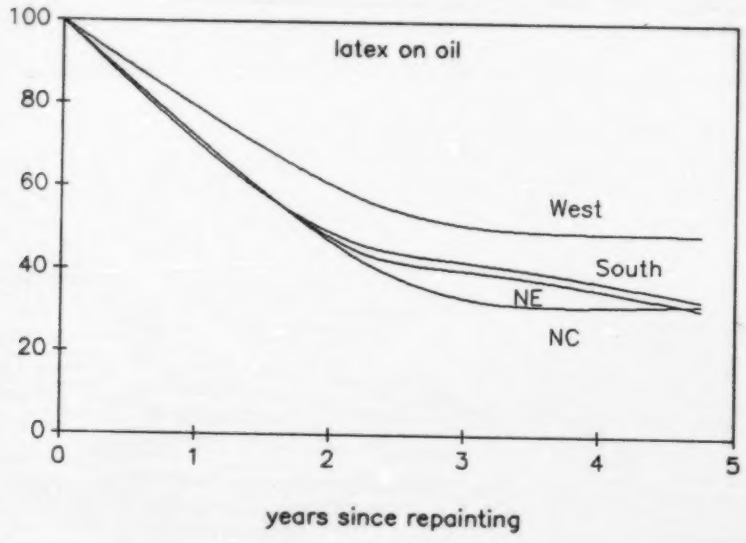

Figure 19. Percent of Respondents Using Latex Paint over Oil Without Problems (1975 mail survey).

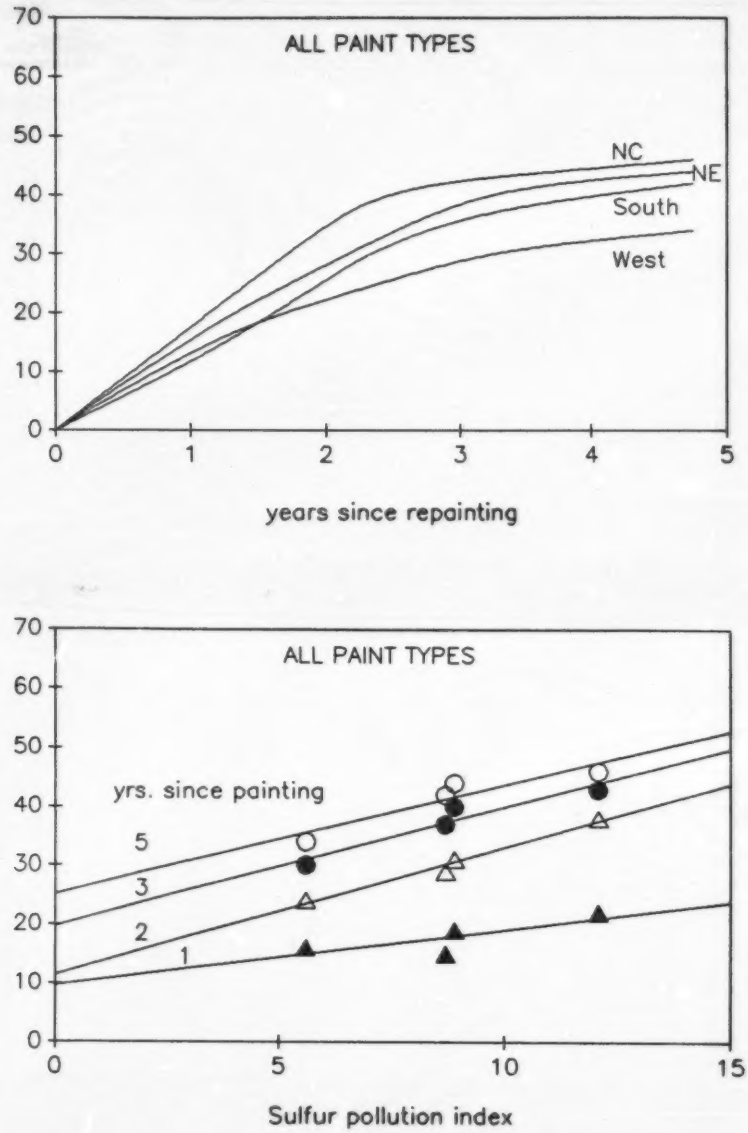

Figure 20. Percent of Respondents With Peeling or Flaking (1975 mail survey). (a) all paint types by region. (b) all paint types by sulfur air pollution index.

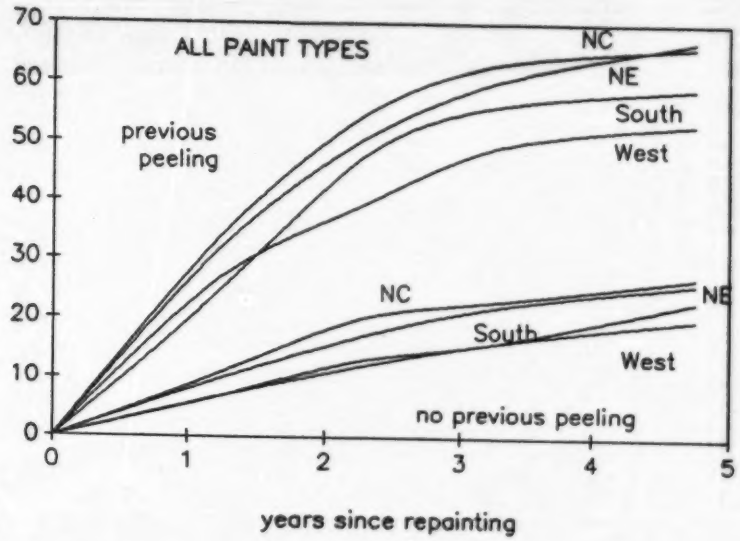

Figure 21. Percent of Respondents With Peeling or Flaking (1975 mail survey), by Previous Peeling.

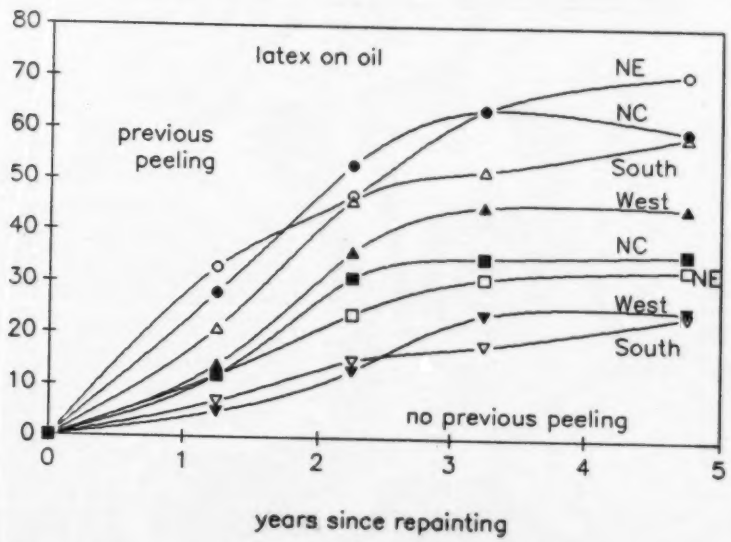

Figure 22. Percent of Respondents Using Latex Paint Over Oil, With Peeling or Flaking (1975 mail survey), by Previous Peeling.

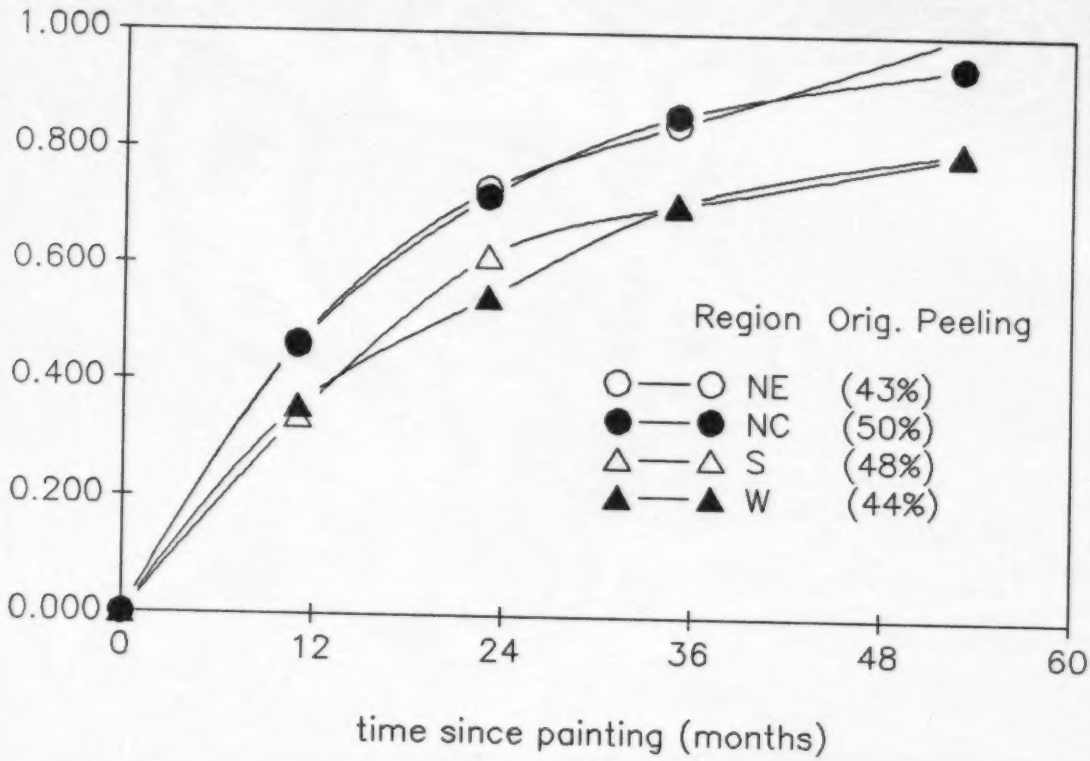

Figure 23. Fraction of Previously-Peeled Houses with Peeling (1975 mail survey).

Consumer Panel Surveys

Another organization has been polling nationally representative panels of about 500 consumers periodically since 1976. Their emphasis has been more towards market surveys. Like the above survey, respondents tend to be better educated and more economically advantaged than the general public. 88% of the panel owned their own homes, which were reported to be primarily single-family residences.

In the most recent survey (April 1987), exterior paints and stains (as defined by the manufacturers) were compared. Of those painting or staining within the last three years (52%), 30% used stain, and of those, 89% were satisfied with the results. From the wording of this question, it is possible to assume that some portion of the 48% who did not paint or stain hired professionals to do so.

In October 1986, the panel was polled about painting exterior house walls and trim. This survey protocol allowed multiple responses, which complicates the data analysis, since no information was provided on combinations of responses. However, based on the numbers of "no responses" for various questions we deduced that 83% of this panel had painted trim and 58% had painted walls. Given that only 88% are likely to have done any painting in any event (since they were homeowners), these results seem to imply a higher-than-average tendency towards painted walls. The houses were about 28 years old on average (Figure 24 gives the age distribution) and the responses implied an average life of 30 months of the most recent previous painting. The parts of the buildings that were painted are given in Figure 25; the responses for components other than walls and trim are appreciable. All percentages other than "no answer" are based on the fraction responding (93%). The average amount of paint used was about 6 gallons, which would correspond to about 2400 square feet for one coat and compares well with the 1982 slope on Figure 14. Only about 20% reported using enough paint to cover an "average" house with two coats.

Figure 26 displays the reasons given for painting walls and trim. Since "peeling," "blistering," "cracking," and "flaking" are terms which may be used somewhat interchangeably by a lay person, it is not clear whether these responses should be added. They total about 44% of the total mentions (which average about three per respondent), without distinguishing walls or trim. For trim, they total 45% of mentions; for walls, 25% of mentions. 13% of the trim painting mentions and 9% of the wall painting mentions were "to change colors," but it cannot be determined if some forms of paint damage were also present. Only 0.5% of the responses were "no visible damage, preparing to sell house." Although the percentages of peeling responses may be similar to those from the 1975 mail survey, the erosion responses are substantially fewer. The questionnaire included a response for "acid rain" damage, even though there is virtually no way for a homeowner to identify such damage. A representative from the sponsoring organization thought that some of these responses reflected their knowledge of the presence of acid rain in their area. It was also of interest to note that the panel would be willing to pay an average of $5.86 per gallon more for a paint that was "resistant to acid rain," which was about the same amount as they reported being willing to pay for most of the other desirable paint attributes listed.

The panel reported that on average they decided to repaint when about 25% of the area was visibly damaged, although these responses ranged from "none" (15% for walls and 8% for trim) to 75-100% (about 5%). The panel clearly opted for painting well before the 50% damage level. The data on the sides showing damage first are displayed in Figure 27. It is not clear whether the "no answers" correspond to the lack of a clear distinction or simply failure to answer the question.

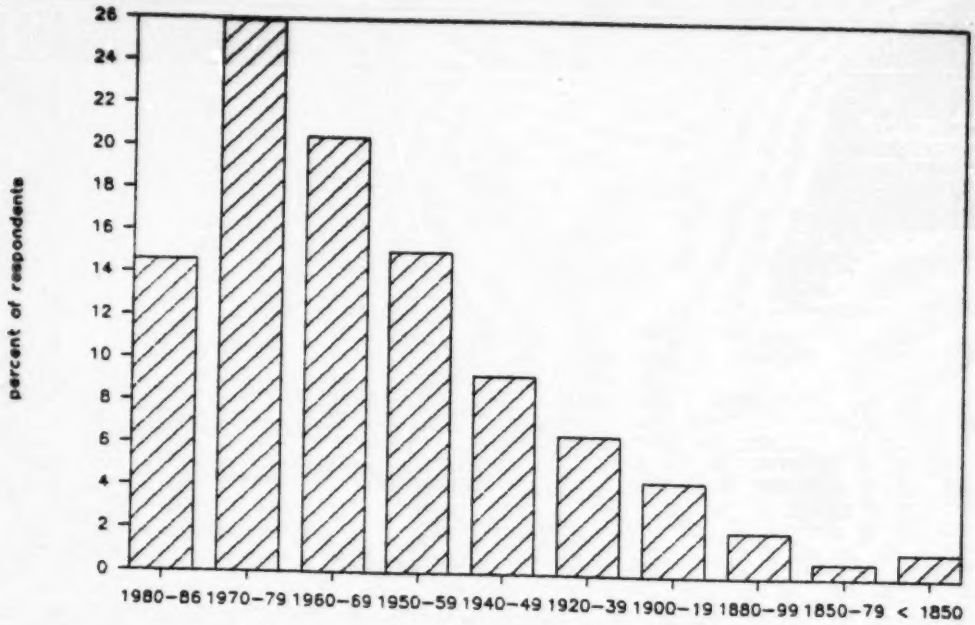

Figure 24. Distribution of Year of Home/Apartment Construction (1986 panel survey).

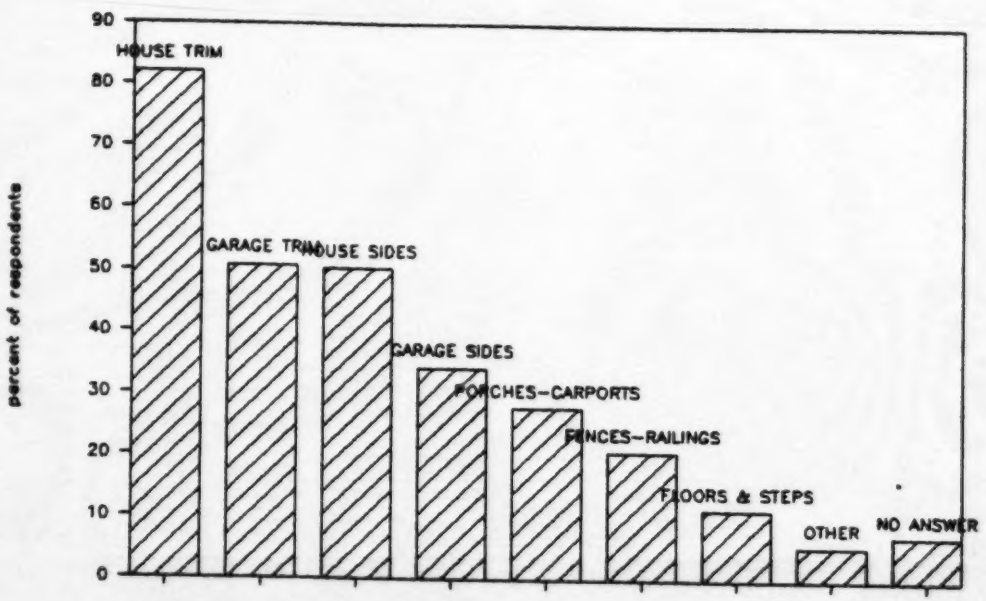

Figure 25. Areas Painted, 1986 Panel Survey (multiple responses)

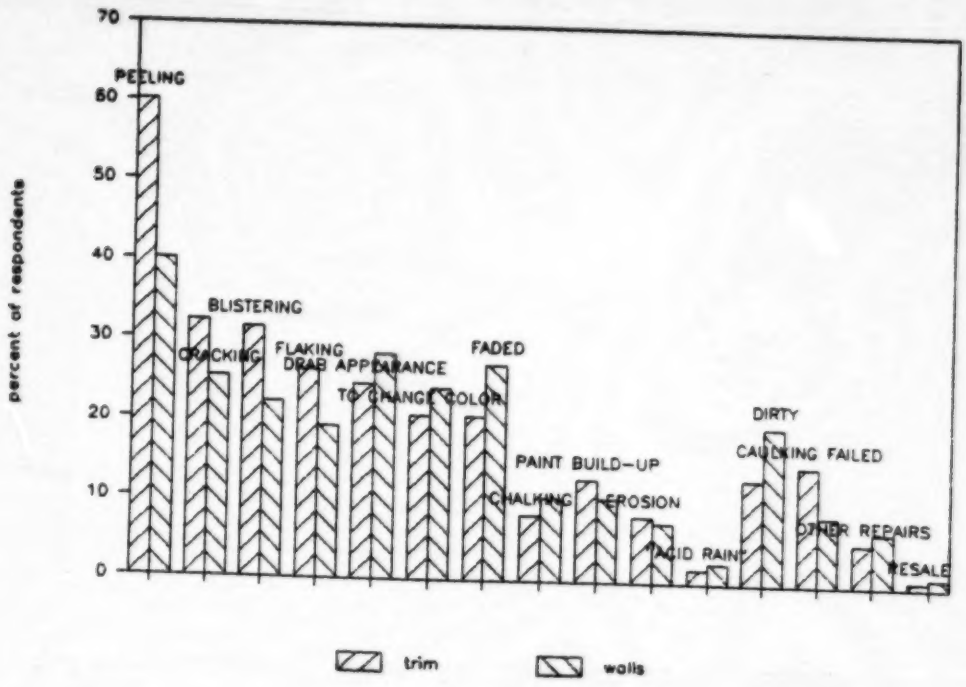

Figure 26. Reasons for Repainting (1986 panel survey).

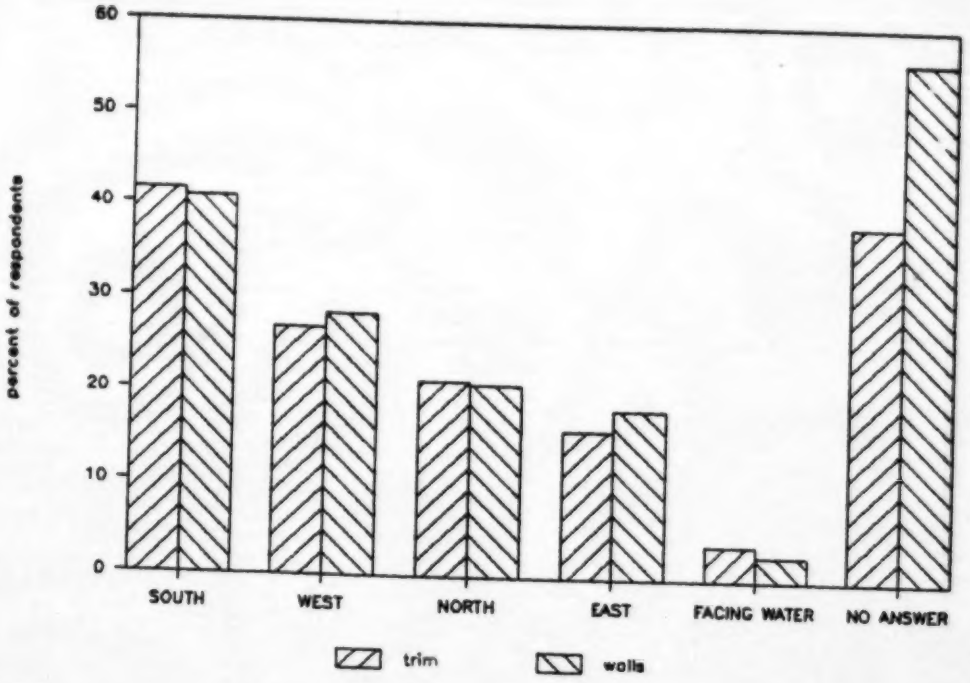

Figure 27. Distribution of Sides of Structure First Showing Paint Damage in 1986 Panel Survey (multiple responses).

The types of paint used are given in Figure 28, which are overwhelmingly latex for both "this" painting and the previous. In addition, 73% reported that they did not switch types. 69% reported that they painted all the trim at once (rather than just the parts that need painting), and 76% did so for walls. 30% used contract labor for trim and 33% for walls. In the remaining cases, the husband reported doing most of the painting. The panel reported that they expected their most recent paint job to last an average of about 3.7 years.

The 1983 panel answered questions on their tendency to be a "do-it-yourselfer." 97.5% of the men and 79.5% of the women reported that they had ever done exterior painting or staining. 71% of the women characterized themselves as "do-it-yourselfers"and 57% thought they were more likely to be so than other women they knew.

In March 1981, paint buying habits were examined. 62% of the panel reported buying exterior paint "recently," 68% of which was latex. Only 5% reported dissatisfaction with the paint brand they purchased, although another 19% were only "moderately satisfied." Durability was the most important paint characteristic. 46% of the panel reported changing remodeling plans because of economic conditions.

In August 1981, a similar panel was queried on various paint topics, with the following results. 70% of the sample (80% of the respondents) had homes which required exterior painting. The average time since the last painting was about three years. 65% of these homeowners did their own painting; 27% used professional painters. 65% used latex and 28% used oil-based paints. 64% were satisfied with their paint job, and 36% reported some peeling. Of those who were not completely satisfied, peeling was the problem mentioned most often with "didn't last" next. Over half of this sample lived within five miles of a body of water.

Other Surveys

Since the above surveys may suffer from a bias in the population sampled, results from a randomized survey may be of interest (Decorative Products World, 1982). 400 interviews were conducted in shopping centers in New Jersey, Georgia, Iowa, and California. 46% reported "paint failure" as their reason for repainting, 35% said that the paint "didn't look good" (color loss?), and 19% that they wanted to change color. In spite of the high indicated failure rate, the mean satisfaction rating on a scale from 1 to 10 was 8.2, which seems to indicate rather low expectations for paint performance. These respondents indicated an awareness of the need for adequate surface preparation, and an average thought that 45% of the total painting job time was associated with surface preparation.

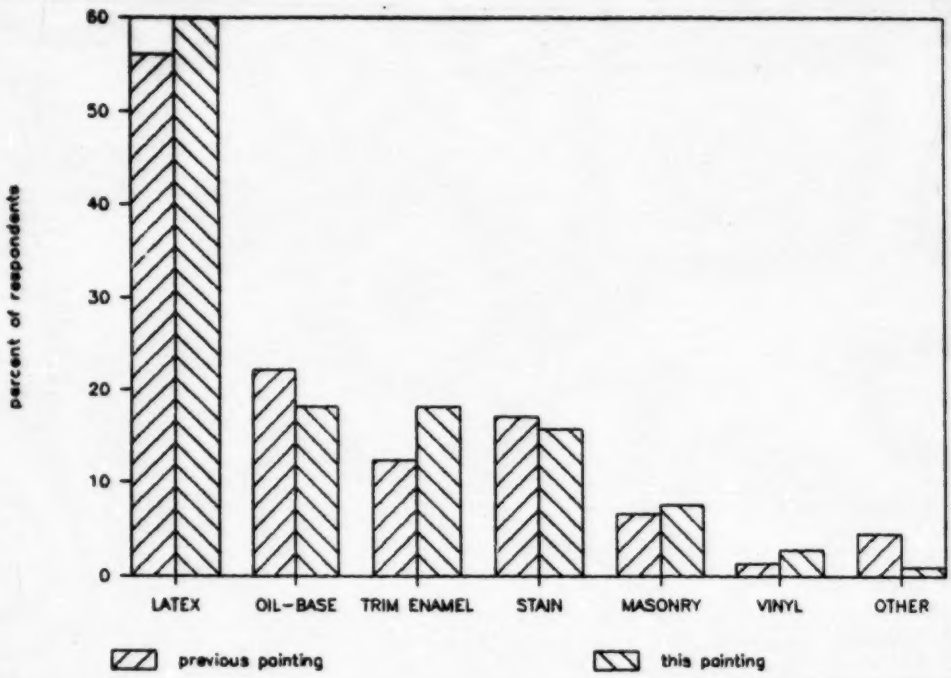

Figure 28. Types of Paint Used (1986 panel survey).

SECTION 4

RESEARCH RECOMMENDATIONS

One of the purposes of this analysis is to derive a list of paint types and applications that should be given priority for research into the effects of acid deposition on coating system life. By application, we essentially mean to specify the substrate that should be used in laboratory and field investigations.

In order for materials damage research to be both practical and relevant, two interdependent criteria should be used to select the materials for study: abundance in the economy and sensitivity to damage. These two criteria tend to be mutually exclusive in the portions of the country subject to acid deposition, since informed property owners will tend to select those materials and coating systems that have been shown to hold up well (insensitive). This may be less true for house paints, since information on their relative durability is not widely available.

SELECTIONS ACCORDING TO RELATIVE ABUNDANCE

Table 1 showed that architectural coatings represented the largest dollar amount of installed cost among the various categories of exterior paint application. Figure 6 showed that within this category, residential buildings were the most important. Taking into account do-it-yourself labor opportunity costs, we concluded that residential maintenance painting was more important than new construction. Surveys show that latex paint is the most common type used; thus the first paint/substrate to be recommended on the basis of abundance is latex over a previously painted surface. Since new construction trends seem to favor factory-primed siding, the next ranking on the basis of abundance should include either plywood or hardboard siding, again with a latex topcoat.

SELECTIONS ON THE BASIS OF RELATIVE SENSITIVITY TO ACIDIC DEPOSITION

The most sensitive constituent of commonly used paints appears to be calcium carbonate extender. Paints containing this ingredient are thus the first priority according to sensitivity. Specific applications should include a high-gloss oil-based trim paint and a chalking white, applied over new or primed wood. The most sensitive substrate is probably structural steel; since the alkyds are the least durable of the maintenance paints, alkyd over steel would constitute the most sensitive choice in the maintenance paint category.

SECTION 5

CONCLUSIONS

This study has shown that residential buildings are the most economically important subset of the painted structures in the U.S. in terms of the costs of painting. The trends for new construction indicate that this ranking is likely to continue in the future. Although both new construction and maintenance painting are economically important, the more difficult conditions involved in painting over existing
finishes make this an important class of situations for research. Automobile finishes are a high-value use of paint, but the importance of acid deposition as a reason to repaint has not been established.

The most important mode of paint failure appears to be "peeling," which, in its various manifestations, accounts for about half of residential paint problems. Such problems often occur within two to three years after painting. Color changes (deterioration) are next in importance. Although chalking and erosion have been observed, their roles in decisions to repaint are less apparent. Paints containing acid-sensitive components may be found in today's retail market at all price ranges, especially oil-based glossy paints. Painting solely to change color or for resale of the property appears to be of minor importance.

The trends in paint usage and performance are generally supportive of (or at least not inconsistent with) the hypothesis that air pollution or acid rain may be having some adverse effects, although such data are by no means conclusive. Selections of coatings and substrates for acid deposition research should include both those combinations that are widely used (latex over wood and over previous paint) and that are sensitive to acid deposition (paints containing $CaCO_3$; alkyd paint over steel).

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APPENDIX A GLOSSARY OF PAINT DEFECT TERMS

Bleaching: Uniform loss of color from clear coatings, transparent stains, or in the color of wood.

Blistering: A film failure at the interface of film and the substrate when there is an elevation of the paint film from the substrate surface.

Chalking: The formation on a pigmented coating of a friable powder evolved from the paint film or from just beneath the surface.

Checking: Film failure with cracking only in the surface of the coating, not penetrating through to the substrate.

Cracking: Breaks in the surface of the film extending through to the substrate.

Dirt: Accumulation of soil or particulate matter adhering to the paint film surface.

Discoloration: A mottled appearance caused by dirt and/or mildew adhering to the paint film surface or by redeposition of pigment extenders onto the paint surface.

Efflorescence: Development of a non-uniform discoloration due to the formation of salts on the surface, usually on masonry or unglazed cement.

Erosion: Irregular removals of coating materials from the paint film.

Fading: Loss of the original color.

Flaking: Severe cracking with pieces of the film detached from the substrate.

Frosting: Surface whitening due to leaching of solubles from the paint surface or the coating beneath it.

Gloss: Changes in superficial luster or brightness from the painted surface.

Loss of Adhesion (Delamination): Detachment of the paint film from the substrate, not due to blistering, flaking, etc.

Mildew: Presence of mold or other micro-organisms on the surface.

Rust Pebbling: Unbroken raising of the paint film due to rust expansion underneath.

Rust Stain: Rust stains on an unbroken paint surface.

Rust Undercut: Lifting of the paint coat at score marks on cracked edges of the film.

Tint Retention: Loss of color due to surface chalk of lighter color than the original paint film.